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ICAM MANUFACTURING COST/DESIGN GUIDE
VOLUME I: DEMONSTRATION SECTIONS

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SEPTEMBER 1980

FINAL REPORT
SEPTEMBER 1977 – JULY 1979

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This technical report has been reviewed and is approved for publication.

Steven R LeClair

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Project Manager

FOR THE COMMANDER

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Manufacturing Technology Division

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Design-to-Cost	Sheet Metal Forming	Part Count
Airframe Design	Aluminum Sheet	Advanced Composites
Fuselage Panels	Titanium Sheet	Graphite/Epoxy
Cost Drivers	Steel Sheet	Laminating

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of the "Manufacturing Cost/Design Guide" (MC/DG) is to enable airframe designers to achieve lowest cost by conducting trade-offs between manufacturing cost and other design factors. When fully developed, the MC/DG will enable designers, at all levels of the design process, to perform quick, simple, cost-trade comparisons of manufacturing processes and structural performance/cost trade-offs on airframe components and subassemblies in metallic and composite materials. To accelerate technology transfer, potential cost saving opportunities offered by emerging materials and

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manufacturing technologies will be indicated in the MC/DG.

The first program, reported in AFML-TR-76-227, developed a model of the MC/DG, the contents, cost drivers, data requirements and designer-oriented formats for conventional and some emerging manufacturing technologies, and also an implementation plan.

The second program (Contract No. F33615-77-C-5027) consisted of four phases in which manufacturing man-hour data and designer-oriented formats were developed for "Sheet-Metal Aerospace Discrete Parts", "First-Level Mechanically Fastened Assemblies", and "Advanced Composite Fabrication". Further, structural performance/manufacturing cost trade studies were conducted by designers in industry utilizing the manufacturing man-hour data developed in this program. Volume I of this report reviews the data development for each of these manufacturing technologies. A family of sheet-metal parts was studied. These represent typical stiffeners, stringers, doublers, frames, ribs, webs, skins, fairings, and brackets each produced by a number of manufacturing processes, such as brake forming, rubber press, Buffalo roll, etc. The materials studied were aluminum alloy, titanium alloy, and steel.

The data developed by the five participating aerospace companies were normalized and the data plotted in designer-oriented formats. Data have been developed for base parts and also discrete parts. The base part is an element in its simplest form and with designer-influenced cost elements (DICE) such as, in the case of sheet metal, joggles, cut-outs, and heat treatment, a discrete part is defined. Typical DICE analyzed for mechanically fastened assemblies are accessibility, material types joined, part and fastener counts, and sealing requirements. For composites, typical DICE are orientation and number of plies, overlaps, fiber mix, cut-outs, and quality requirements.

The data are presented in the series of formats showing cost-driver effects (CDE) and cost-estimating data (CED) and have been tested and evaluated using various fuselage designs in titanium, aluminum, and graphite/epoxy.

The demonstration sections for sheet-metal, mechanically fastened assemblies, and advanced composite fabrication are available to designers both in hard copy and also as a computerized data base. Interactive graphics systems will be necessary for future application in the design process. Volume III of this report discusses in detail the functional requirements of the computerized MC/DG.

PREFACE

This technical report covers the work performed under Contract No. F33615-77-C-5027, from September 19, 1977, through July 19, 1979, by the Battelle's Columbus Laboratories (BCL)/Airframe Industry Team for the Computer Integrated Manufacturing Branch, Materials Laboratory (AFWAL/MLTC), Air Force Wright Aeronautical Laboratories, AFSC, Wright-Patterson Air Force Base, Ohio 45433. The airframe companies and program managers participating under a subcontract with BCL in this program are listed below.

1. USAF TECHNICAL DIRECTION

This program was administered under the technical direction of Capt. Dan L. Shunk, AFWAL/MLTC, and Mr. David Judson, AFWAL/MLTC, who was responsible for the MC/DG Computerization discussed in Volume III.

2. MC/DG COALITION

BCL was the prime contractor on the MC/DG Data Development Program. Mr. Bryan R. Noton, Manager, Design/Manufacturing Interaction Project Office, BCL, was the Program Manager. BCL was supported by the following subcontractors:

Airframe Company Subcontractors	Program Managers
General Dynamics Corporation, Fort Worth Division	Ben E. Kaminski, Phase I Phillip M. Bunting, Phases II and III
Grumman Aerospace Corporation	Vincent T. Padden
Lockheed-California Company	Anthony J. Pillera
Northrop Corporation, Aircraft Group	John R. Hendel
Rockwell International Corporation, Los Angeles Division	Ralph A. Anderson
In Critique Mode: Boeing Commercial Airplane Company	David Weiss, Phases I and II Peter H. Bain, Phase III

3. THE TEAM APPROACH

The team organization chart, indicating staff at BCL and at each team member company participating in this program, is shown on page iii.

Important advantages are evident in the development of manufacturing man-hour data by a team of major aerospace companies. The principal advantages are as follows:

- Provides a cross-section of small and large aircraft for the entire industry; both military and commercial.
- Present team members have large interface with all levels of designers. The MC/DG will, therefore, be transitioned more rapidly by industry to the design process.
- Team draws on each company's expertise making results more viable (expertise and installed manufacturing facilities vary across industry).
- Team has an extensive source of available data and provides a broad base from which to collect and develop data.
- Team provides the required base for deriving average industry data (which cannot be achieved without the team approach).
- Team can verify and thus provide confidence to data and formats for designer use. rather than a parochial point of view of a single company.
- Team has established ground rules and methodologies to develop manufacturing man-hour data and designer-oriented formats.
- Team provides a broad base for emerging technologies and utilization of Air Force manufacturing technology (MT) program results.

TEAM ORGANIZATION ON "MANUFACTURING COST/DESIGN GUIDE" (MC/DG) PROGRAM

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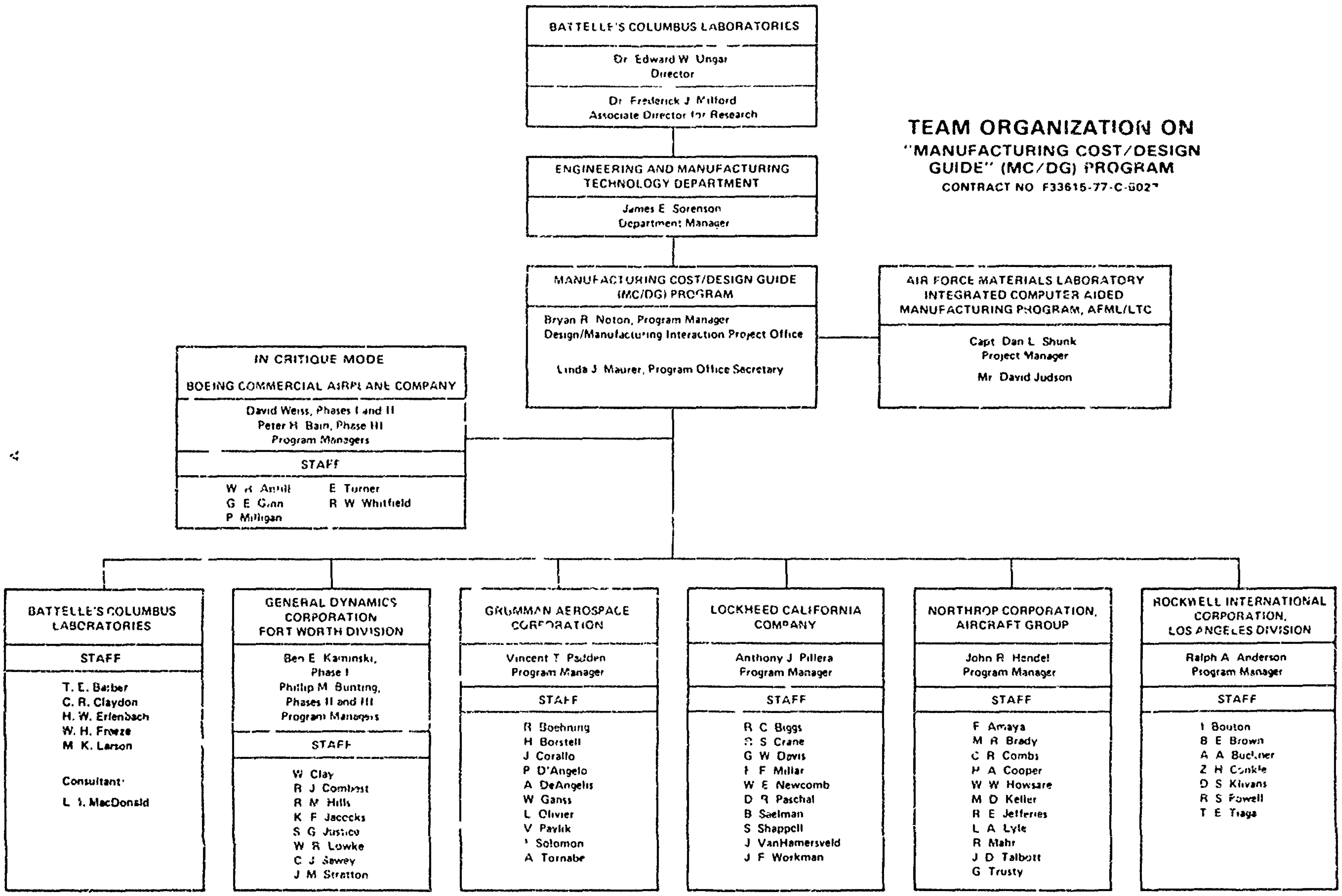

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SECTION I

INTRODUCTION

The challenge of designing-to-lowest cost will become increasingly difficult due to the growing problems of inflation, systems sophistication, and increasing labor costs; the need for affordable performance will continue to play a dominant role, as the problems will influence the ability of DOD to acquire defense systems. The implementation of the "Manufacturing Cost/Design Guide" (MC/DG) by the Computer Integrated Manufacturing Branch, Materials Laboratory (AFWAL/MLTC), Air Force Wright Aeronautical Laboratories, Air Force Systems Command (AFSC), is, therefore, an important step in arresting any potential erosion of ou. defense capabilities and can be expected to substantially alleviate the severe problems of designing-to-lowest cost.

The design teams of both manned and unmanned aircraft, such as cruise missiles, can be motivated into a design-to-lowest cost attitude by utilizing the MC/DG in the design process. Design teams must be provided with:

- Tools: Identification and documentation of cost drivers and cost reduction methods
- Incentives: Cost targets against which performance of design personnel can be measured.

The specific objectives of the MC/DG are as follows:

- To provide structural designers with simple, relative, and quantitative cost comparisons of manufacturing processes that can be rapidly applied
- To emphasize design orientation of MC/DG formats and manufacturing man-hour data for use at all phases of design process, e.g., preliminary and detail design, therefore, increasing emphasis on cost; a vital design parameter
- To enable more extensive structural performance/manufacturing cost trade-offs to be conducted by designers on airframe components and subassemblies
- To emphasize potential cost advantages of emerging materials and manufacturing methods accelerating the transfer of these technologies to production hardware.

In summary, the objective of the MC/DG is to put designers on the lowest cost track early in the design process.

Because of the complex nature of the objectives of designing and manufacturing aircraft systems to the lowest possible cost, manufacturers are turning increasingly to the use of the digital computer for both the design and manufacture of aircraft. The computer-aided concept is the basis of the Air Force's Integrated Computer-Aided Manufacturing program, known as ICAM. ICAM will help industry to revolutionize its approach to improving overall productivity, at all levels of the manufacturing hierarchy, from the shop floor operations to executive decision making.

The MC/DG is one of the most critical parts of the ICAM program. The MC/DG, at this time, covers design, fabrication, and assembly. Future efforts will include test, inspection and evaluation (TI&E), as well as the cost reduction potential of emerging technologies. The thrust areas of these ICAM programs are shown in Figure 1. It will be noted that the following are the thrust areas and planning designations to which the MC/DG is related:

- Fabrication (2000)
- Design (4000)
- Assembly (7000)
- Test, Inspection, and Quality Assurance (0000).

The MC/DG enables the required interaction to be achieved and trade studies to be conducted between aircraft system performance and manufacturing cost, while meeting the developmental schedule requirements. The interactions between performance, manufacturing cost, schedule, and operations and maintenance costs are shown in Figure 2.

The individual designer has seldom been trained or has experience to conduct structural performance/manufacturing cost trade studies in his daily efforts. However, today the designer is rated not only on his ingenuity to meet the weight and cost objectives but also to achieve this within the design schedule limitations (Figure 3). Design-to-lowest cost is now a design discipline.

In the past, the designer had only one resource in determining cost and this was the cost estimator. The cost estimator is still an

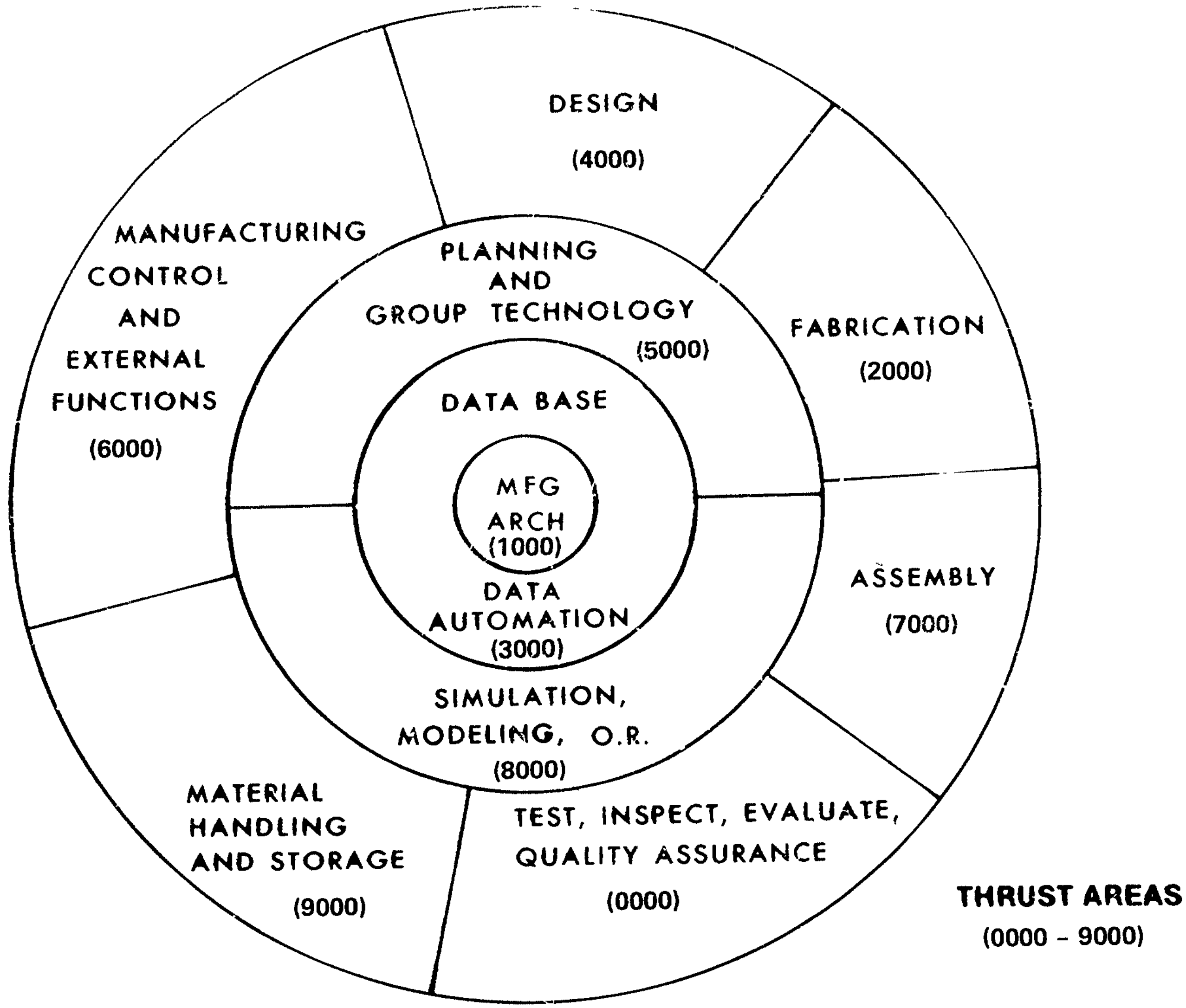

FIGURE 1. AIR FORCE INTEGRATED COMPUTER-AIDED MANUFACTURING (ICAM) THRUST AREAS

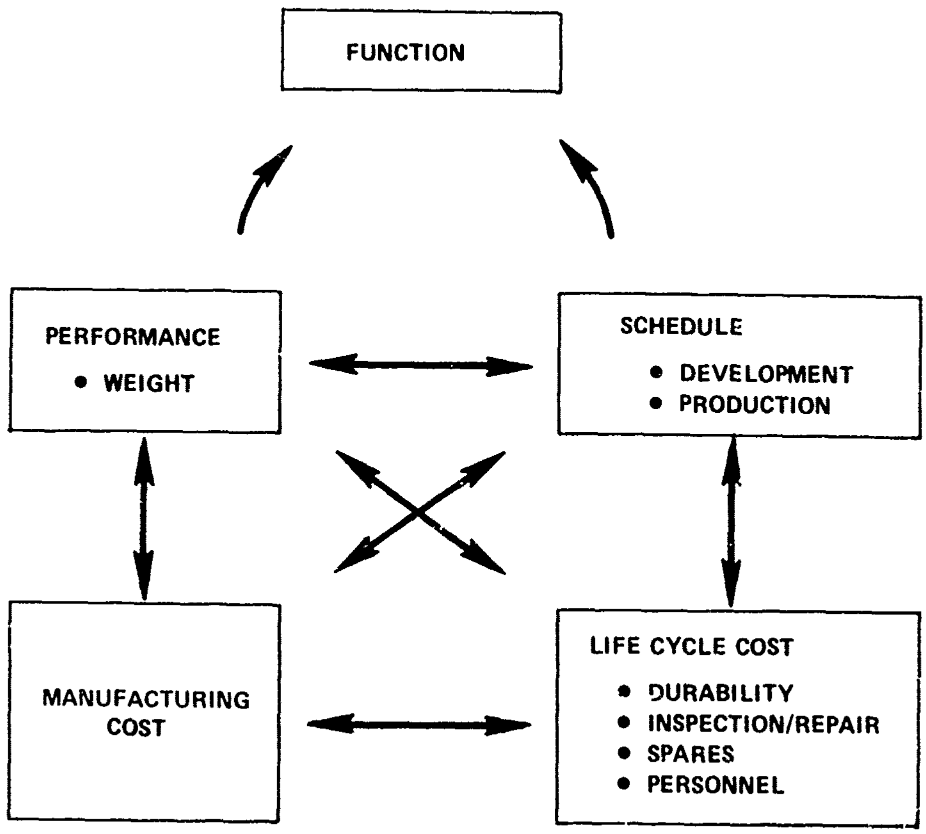

FIGURE 2. INTERACTIONS BETWEEN DESIGN AND OTHER DISCIPLINES

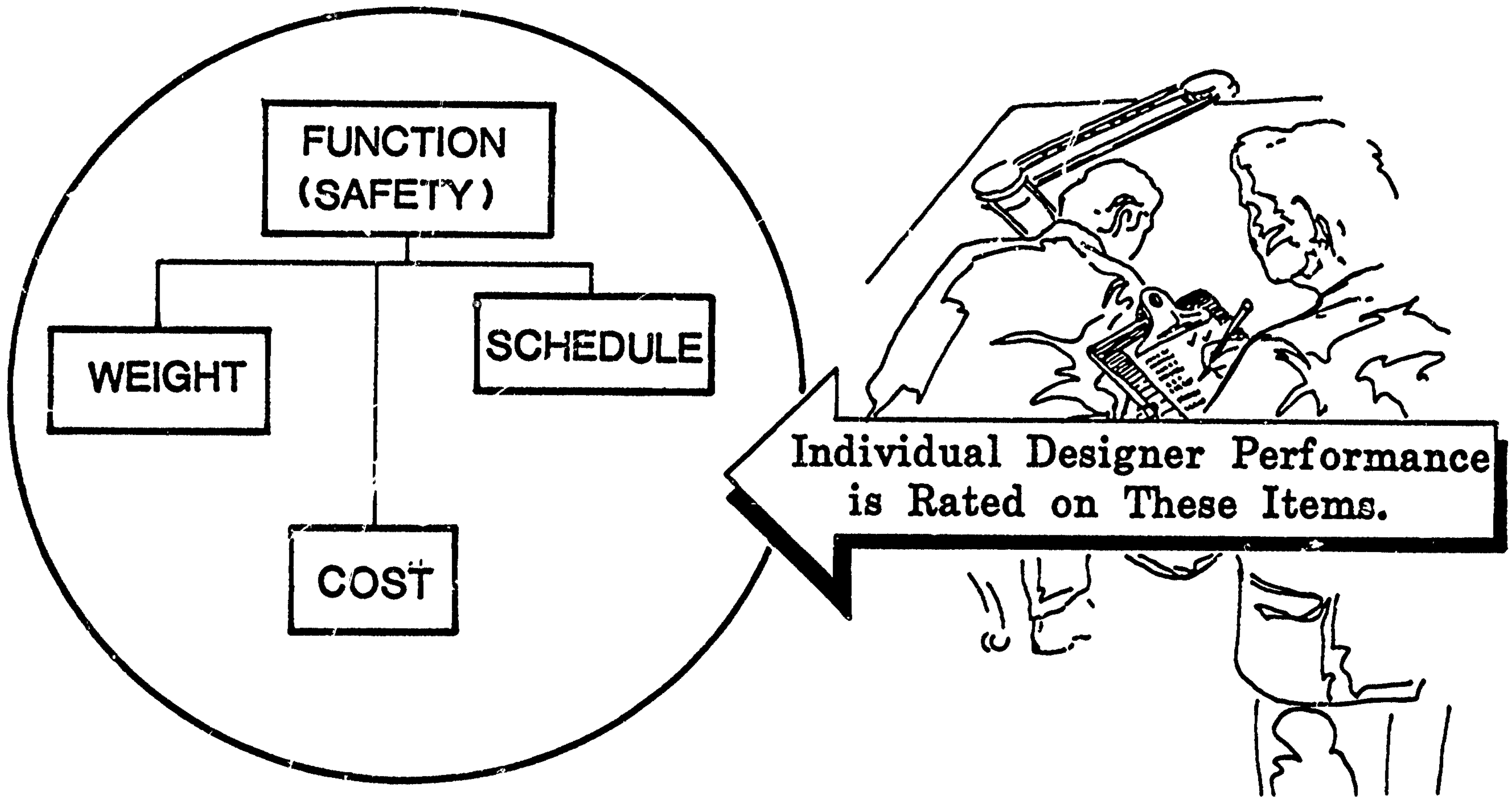

FIGURE 3. PRESENT AIRCRAFT DESIGN TEAM PRIORITIES

important factor in the final iteration of the design prior to production commitment. However, it is often difficult to meet scheduling requirements, as well as to consider an adequate number of design alternatives while ascertaining, with confidence, that the selected design is actually the lowest cost alternative.

While the MC/DG can be used at all levels of the design process, the importance of the preliminary design phase, the "window of opportunity", needs to be emphasized. Figure 4 illustrates how the cost savings leverage decreases as the program progresses. The preliminary design phase is where industry has the maximum opportunity to achieve a low cost design. It is here where radically innovative approaches to structural design concepts and manufacturing technology choice can significantly impact cost. Configuration selection frequently offers the major opportunity to reduce costs. It is at this preliminary design phase, as Figure 4 indicates, where only a few percent of the program costs have been expended, yet decisions have been made which influence 90 to 95 percent of the total cost including operations and maintenance costs. As the program progresses through detail design and production, it is extremely difficuly to reduce the cost by more than a few percent even with innovative approaches to design and manufacturing. As soon as the detail design phase is approached, the majority of components considered for redesign to utilize alternative advanced manufacturing processes or materials must meet Form, Fit, and Function requirements of the part being replaced. Figure 5 shows the cost impact of decisions as a function of the number of decisions. The major milestones are indicated throughout the development of an aircraft system committed to production.

The benefits of an MC/DG developed meeting the objectives specified earlier are summarized below:

- More trade studies possible within available time span resulting in a larger number of alternative designs considered to assure lowest cost
- Manufacturing cost drivers alleviated and addressed at earlier stage in design process than now possible
- MC/DG serves as communications link between design and manufacturing
- MC/DG stimulates designer to develop innovative structural configurations at the PD stage, utilizing the lowest cost

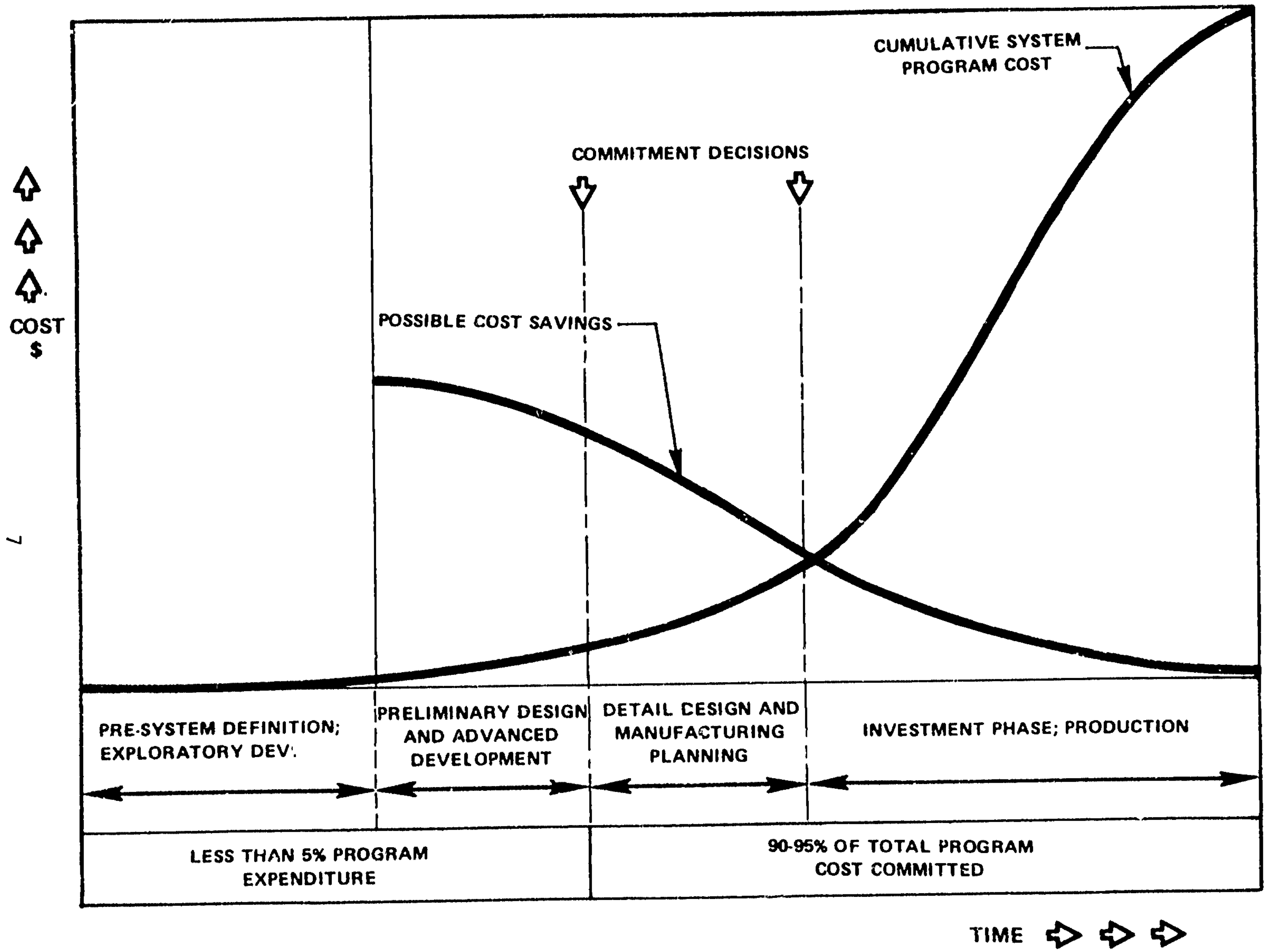

FIGURE 4. DECREASING COST-SAVINGS LEVERAGE AS PROGRAM PROGRESSES

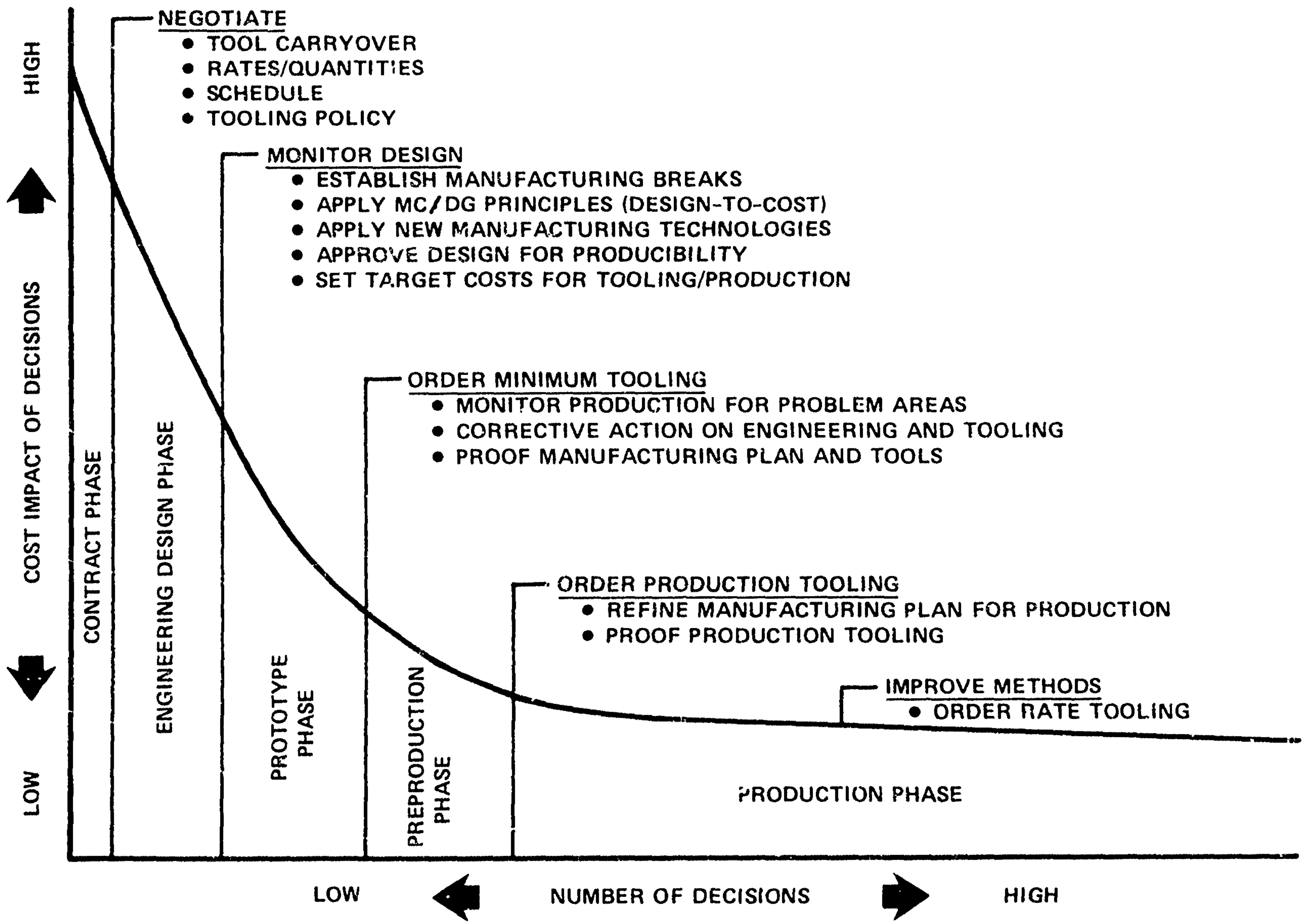

FIGURE 5. IMPACT OF COST ON EARLY DECISIONS

manufacturing technologies for both conventional and emerging technologies.

- MC/DG circumvents problem of limited number of cost studies being made on airframe concepts prior to production release (problem due to time-consuming process of obtaining required cost information estimates).
- MC/DG will support detail design decisions in selecting a design approach at the designer/group leader level permitting faster decisions avoiding need of higher level direction.
- Decisions supported by hard facts made at design layout table.
- Greater breadth provided to designer; problem minimized of "point" designer selecting too narrow a scope, resulting in penalties later in the program.
- MC/DG educates designers with varying levels of experience on less costly alternatives improving future design.
- MC/DG serves as training tool for young or less experienced designers, equiping them to actively participate in design-to-lowest cost programs.

The development of the MC/DG is shown in Figures 6 through 9.

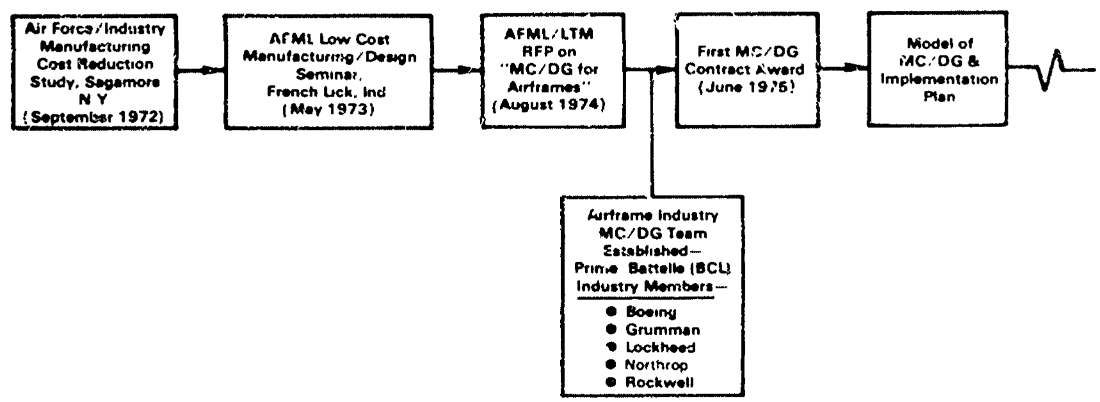

FIGURE 6. AFML "MANUFACTURING COST/DESIGN GUIDE (MC/DG)" DEVELOPMENT - 1

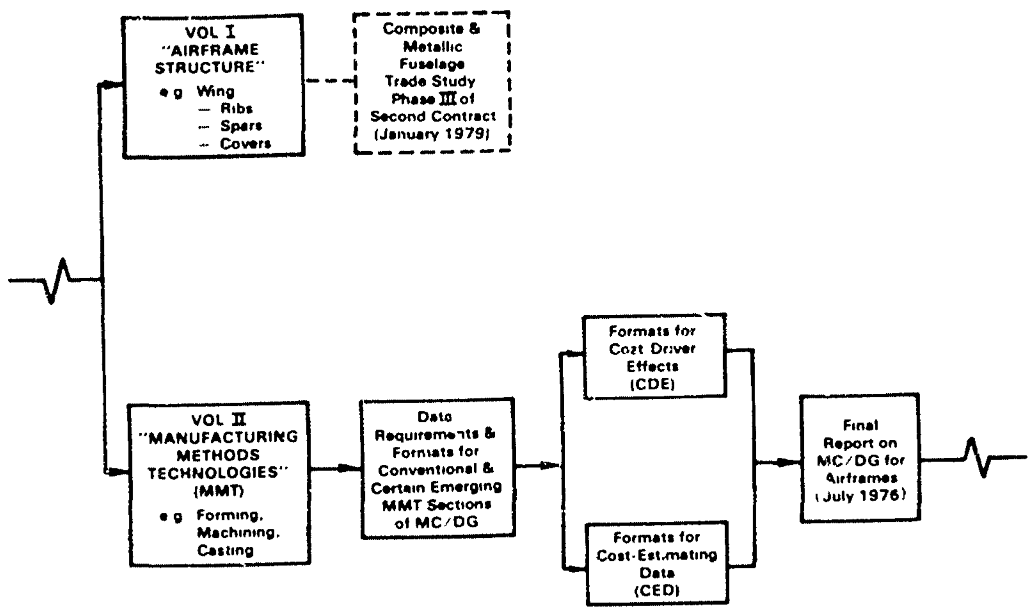

FIGURE 7. AFML "MANUFACTURING COST/DESIGN GUIDE (MC/DG)" DEVELOPMENT - 2

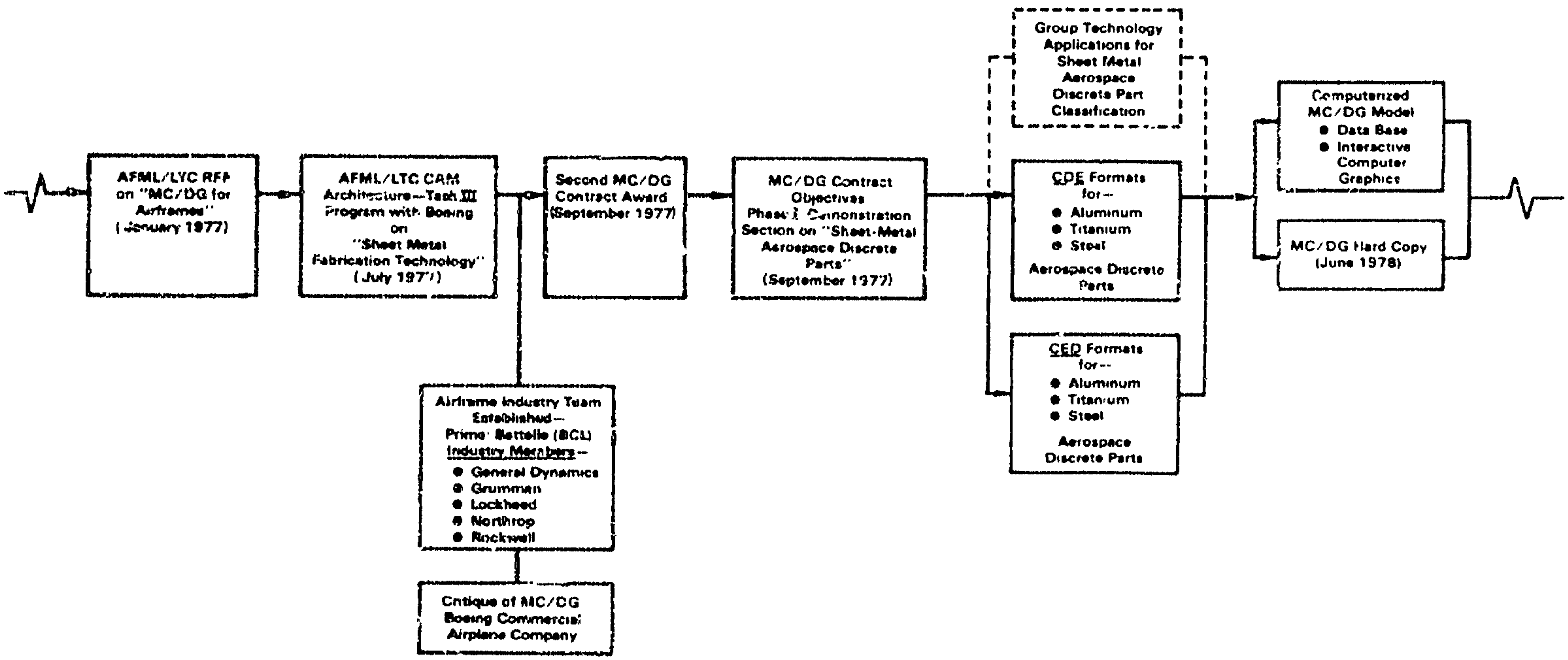

FIGURE 8. AFML "MANUFACTURING COST/DESIGN GUIDE (MC/DG)" DEVELOPMENT - 3

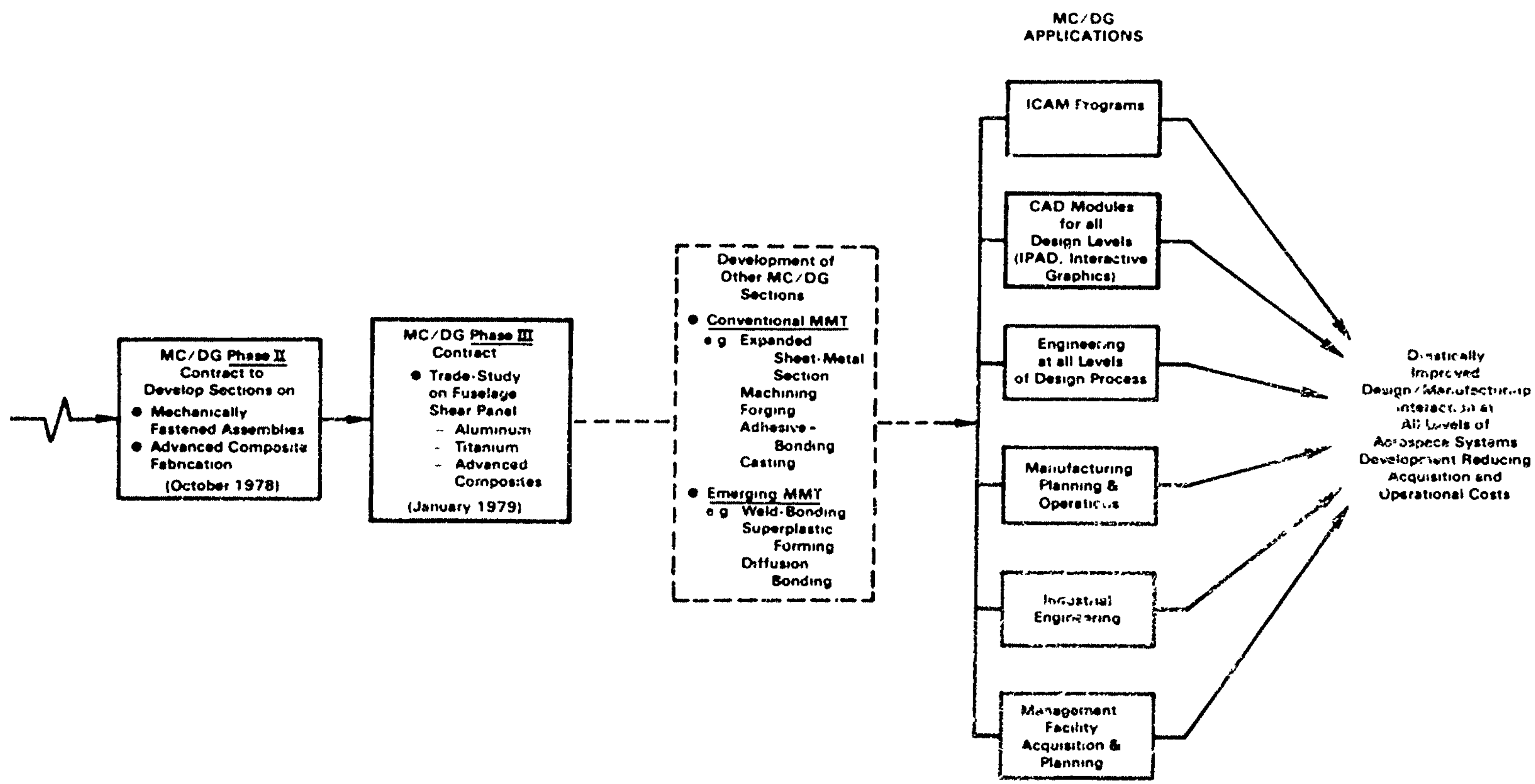

FIGURE 9. AFML "MANUFACTURING COST/DESIGN GUIDE (MC/DG)" DEVELOPMENT - 4

SECTION II

OBJECTIVES OF MC/DG PROGRAMS

Two contracts have been awarded in the development of the MC/DG. The first, a 1-year program (Contract No. F33615-75-C-5194), was completed in July, 1976. The results of this first contract are reported in AFML-TR-76-227. The principal objectives were to:

- Identify the Data Requirements for the MC/DG for both conventional and emerging manufacturing technologies.
- Identify the Basic Format Design Criteria and create formats displaying cost-driver effects (CDE) and cost-estimating data (CED) for each section or manufacturing technology in the MC/DG.
- Prepare a detailed Model of the MC/DG for industry examination. The model consisted of a section-by-section layout of all sections, including sample data sheets and formats for each conventional and emerging manufacturing technology.
- Prepare an Implementation Plan for the MC/DG, i.e., define the mechanisms to develop and/or collect CDE and CED data for insertion in the designer-oriented formats.

The objectives of the second contract, a 15-month program, awarded in September, 1977 (Contract No. F33615-77-C-5027), is discussed in this report. The objectives were to implement certain Demonstration Sections of the MC/DG. The sections selected by the Computer Integrated Manufacturing Branch, AFWAL/MLTC, were:

- Sheet-Metal Aerospace Discrete Parts: Phase I
- First-Level Mechanically Fastened Assemblies: Phase II(a)
- Advanced Composite Fabrication: Phase II(b).

An objective of this program was also to utilize the data developed and the designer-oriented formats for actual trade studies on fuselage shear panels--Phase III.

The contents of the MC/DG volume are shown in Figure 10. It will be noted in Figure 10 that Phases I and II(b) above are part of the MC/DG section identified under the manufacturing category, "Detail

I	II	III	IV	V	VI
PROCURED ITEM COSTS	MATERIAL REMOVAL COSTS	DETAIL FABRICATION COSTS	MATERIAL TREATMENT COSTS	PERMANENT JOINING* COSTS	ASSEMBLY * COSTS
• Forgings Hand Conventional Blocker Precision • Castings Sand Permanent Mold Investment Die Casting • Extrusions • Materials • Fastener Systems • Emerging Proc Isothermal Forging Powdered Metal Pultrusion HIP Healing CAM	• Machining Turning Milling Drilling • Chem Milling • EDM • ECM • Emerging Proc. Laser Fluid-Jet CAM EB Cutting	• Metallic Forming Cutting • Non-Metallics Forming Cutting Molding Laminating • Emerging Proc. Superplastic Forming Flow Forming Hydrostatic Forming Thermoplastic Forming CAM	• Heat Treatment • Surface Treatment • Emerging Proc. Laser Treating Nonenvironmental Polluting Treatments	• Welding • Adhesive Bonding • Brazing • Emerging Proc. Diffusion Bonding Weld Bonding Laser Welding Ultrasonic Welding Plasma Arc *Subassembly	• Metallic Assy. Mechanical Fastening • Non-Metallic Assy. Mechanical Fastening • Emerging Proc. Bimetallic Rivets Microwave Curing *Major and Final Assembly

Categories = e.g., Material Removal
Sections = e.g., Machining
Subsections = e.g., Turning and Milling

FIGURE 10. VOLUME I: MANUFACTURING TECHNOLOGIES

Fabrication Costs". Phase II(a) is identified in Figure 10 under the manufacturing categories, "Assembly Costs".

Phase III represents a typical example of the application of the MC/DG volume, "Manufacturing Technologies", to an airframe point design utilizing conventional structural analysis techniques. An overview of the three phases of the program, described in this report, is shown in Figure 11. This program also has seven subobjectives. These are:

(1) Systematically organize cost data for sheet-metal manufacturing methods

(2) Identify high cost processes involved in manufacturing sheet-metal aerospace discrete parts

(3) Identify high cost materials involved in manufacturing aerospace discrete parts

(4) Test and refine the formats developed in the first AFML MC/DG program (Contract No. F33615-75-C-5194) utilizing actual data from Subobjective (1) above

(5) Establish the MC/DG for advanced composites and first-level mechanically-fastened assemblies

(6) Provide the basis of extension of the MC/DG to all other manufacturing cost centers

(7) Conduct trade studies utilizing the MC/DG demonstration section for sheet-metal, advanced composites, and first-level mechanically fastened assemblies.

The development and implementation of a Demonstration Section for the MC/DG requires the accomplishment of the following tasks:

Task 1

- Formulate general and detailed ground rules
- Develop glossary
- Reassess data requirements and formats from Contract No. F33615-75-C-5194
- Develop data collection procedures and forms
- Develop dimensioned sketches of discrete parts and/or assemblies

Task 2

- Develop and assemble data

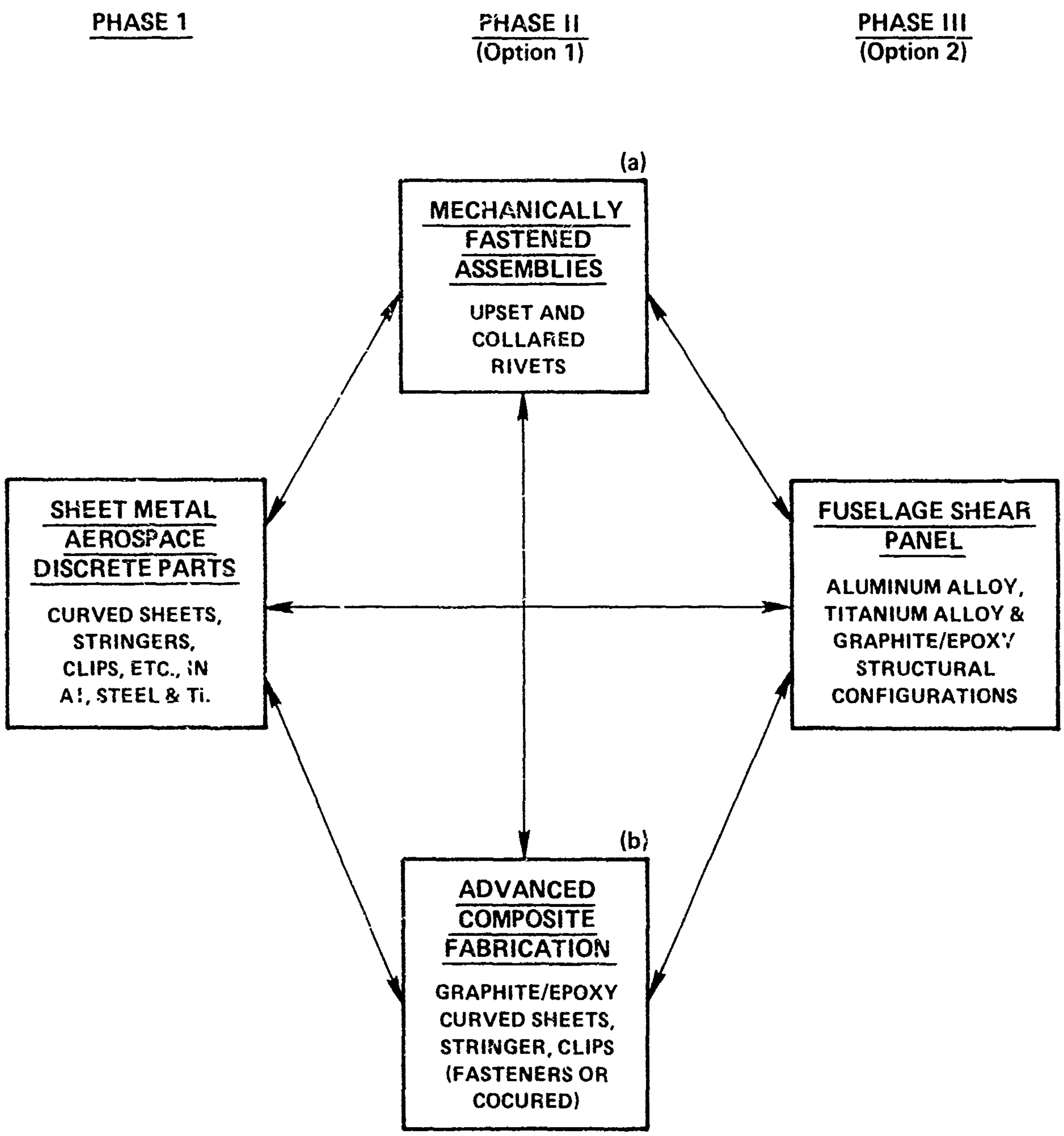

FIGURE 11. INTERACTION OF MC/DG PROGRAM PHASES SHOWING RELATIONSHIP BETWEEN MATERIALS, PART CONFIGURATIONS, AND JOINING TECHNIQUES

Task 3

- Normalize data developed by aerospace team members

Task 4

- Develop formats from those presented in MC/DG model (AFML-TR-76-227)

Task 5

- Incorporate manufacturing man-hour data and relative cost data into designer-oriented formats

Task 6

- Insert in MC/DG.

Utilizing the $IDEF_0$ representation, these principal tasks are shown in Figure 12.

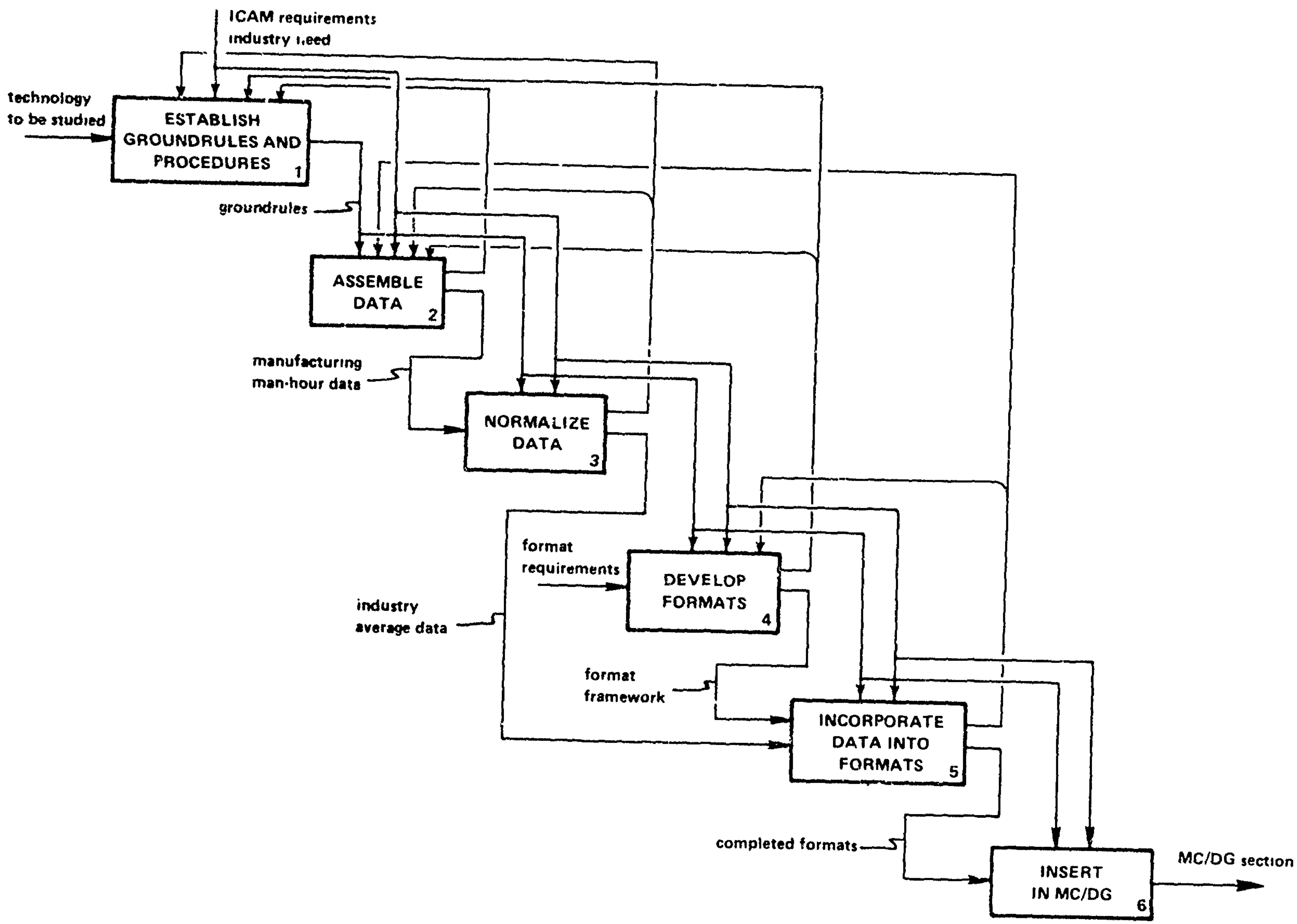

FIGURE 12. MAJOR MC/DG SECTION TASKS

SECTION III

MC/DG AND COST ESTIMATING MANUALS

The MC/DG team analyzed and assessed Cost-Estimating Manuals (CEM) and compared the objectives and organization of these with those of the MC/DG. The following are the principal differences:

- A CEM is not designer oriented. It is an estimating tool used primarily by cost estimators.
- A CEM does not meet the MC/DG development criteria.
- A CEM format is, therefore, not simple for designers to use. It is time-consuming and involves complex calculations which will severely conflict with design schedules.
- A CEM does not illustrate or emphasize cost drivers.
- A CEM does not present relative cost trade-off data (CDEs) in a form readily accessible by designers at different levels of the design process.
- The number of cost-trades, which can be conducted by the airframe industry on different designs involving different manufacturing methods, are limited because of the features of CEMs and the limited number of experienced cost estimators available.

SECTION IV

DESIGNER-ORIENTED FORMAT DESIGN CRITERIA

The designer-oriented formats presented in the model of the MC/DG (AFML-TR-76-227) were reviewed by interdisciplinary groups at BCL and at each company during their development. Each program manager was responsible for the following categories of persons to review the data requirements and formats:

- Management (concurrence necessary to assure MC/DG utilization)
- Engineering (design and support)
- Manufacturing (fabrication, tooling, and quality control)
- Procurement (materials, parts, and equipment).

Furthermore, designer surveys were conducted and the feedback received on the MC/DG was as follows:

- Must be simple whenever possible
- Must not be time consuming to use in the design process
- Complicated calculations should be avoided
- Manufacturing data are urgently needed but with designer orientation
- No single airframe company can provide all manufacturing cost data required due to varying expertise
- Designers are more concerned that it is the lowest cost rather than what it costs, i.e., qualitative comparisons are important.

The MC/DG team agreed that the CDE and CED formats must meet the following criteria:

- Emphasize cost drivers
- Be simple to use
- Use designer language
- Instill confidence
- Be economical
- Be accessible
- Be maintainable.

The following is a detailed explanation of these format development criteria.

1. EMPHASIZE COST DRIVERS

Sensitive factors, which, by minor variation in selection, can cause major increases or decreases in manufacturing cost, will be emphasized in the MC/DG. The degree of impact on manufacturing cost during the design developed through the selection of materials, manufacturing, and fabrication processes must be depicted in formats and data in such a manner as to make the designer readily aware of those elements of design (cost drivers) that pose manufacturing cost hazards.

2. BE SIMPLE TO USE

Guidance to designers will be presented in CDE and CED formats such that there is a minimum or no arithmetical calculations required to determine the cost comparisons of design/manufacturing alternatives. The cost impact formats and graphics will provide more direct read-out of man-hours through maximum use of simple curves and tables.

3. USE DESIGNER LANGUAGE

The primary purpose of the MC/DG is to display manufacturing process capabilities and costs in such a manner that it will permit designers to select the most economical manufacturing approach. The formats must be developed through a close working relationship with design personnel at all the team member companies and through constructive recommendations submitted during the development of the MC/DG. The charts and terminology included with the formats must be common to the engineering community and be of the types which are recognized and employed by the designer in his daily engineering tasks.

4. INSTILL CONFIDENCE

The designer must have a high degree of confidence in the CDE and CED formats and manufacturing man-hour data if the MC/DG is to serve as a useful working tool for design. The formats developed will be related to practical and meaningful cost trades that are illustrative of airframe design decisions made every day by designers. The formats must clearly provide an MC/DG for making trade-off decisions between manufacturing technologies with both comparative and quantitative cost data. It is recognized that the degree of accuracy of manufacturing man-hour data integrated into the formats will be a significant factor in determination of the confidence and degree of utilization of the MC/DG in industry.

5. BE ECONOMICAL

A high priority item in the development of the MC/DG is to reduce acquisition and maintenance costs of the data and formats to a minimum.

6. BE ACCESSIBLE

The MC/DG must be physically and readily available at all designer locations. This will be handled differently within each company, but along similar lines. Copies of the MC/DG can be issued to individual designers or small engineering groups. The wider distribution of the MC/DG to individual users, the more extensive use can be expected. The breadth and distribution would be weighed between the ease of access by individual designers and the cost of distribution. Computerization will greatly enhance the accessibility.

7. BE MAINTAINABLE

The formats must be developed to facilitate the maintenance of the MC/DG. In today's highly fluid technical and economic environment, the useful life of the MC/DG will be dependent upon the flexibility of the formats to accept revised or new data. One approach is through computer preparation of individual pages of loose-leaf-type volumes. The data would be stored in the central data bank and, for user accessibility, transmitted via telephone connections to remote terminals to each company for printout and multiple distribution. This is discussed in Volume II of this report dealing with MC/DG computerization.

The data requirements and MC/DG formats were reviewed at team member companies by:

- Management
- Engineering (design and support)
- Manufacturing (fabrication, tooling, and quality control)
- Procurement (materials, parts, and equipment).

SECTION V

METHODOLOGIES FOR PRESENTING MANUFACTURING MAN-HOUR DATA

The manufacturing man-hour data for the various materials, aerospace discrete parts and assemblies, and manufacturing technologies are presented in two ways. Firstly, cost-driver effects (CDE) and, secondly, cost-estimating data (CED) are shown. The objectives of the CDE and CED methodologies are:

- To develop a simple approach for the use of formatted data by designers to achieve lowest manufacturing costs during all design phases (CDE and CED)
- To provide qualitative cost guidance to the designer to assure lowest manufacturing cost (CDE)
- To provide the designer with the capability through quantitative guidance to perform simple trade-offs on manufacturing costs (CED).

The CDE cost relationships, providing qualitative information, have the following objectives:

- Identify cost drivers that increase the manufacturing cost of the design
- Show relative effects of cost elements over which designers have control
- Motivate designers to reduce the impact of the cost drivers by designing around them.

Using the CDE approach, the designer should realize the lowest cost while satisfying the performance requirements, e.g., airframe weight and durability.

The CED cost relationships, providing quantitative information, have the following objectives:

- Provide designers with manufacturing man-hour data to allow trade-offs to be quickly performed to achieve comparative cost for candidate structural configurations
- Motivate designers to conduct trade-offs through the use of designer-oriented formats and manufacturing man-hour data in the MC/DG.

The presentation of CDE and CED formats is shown in Figure 13.

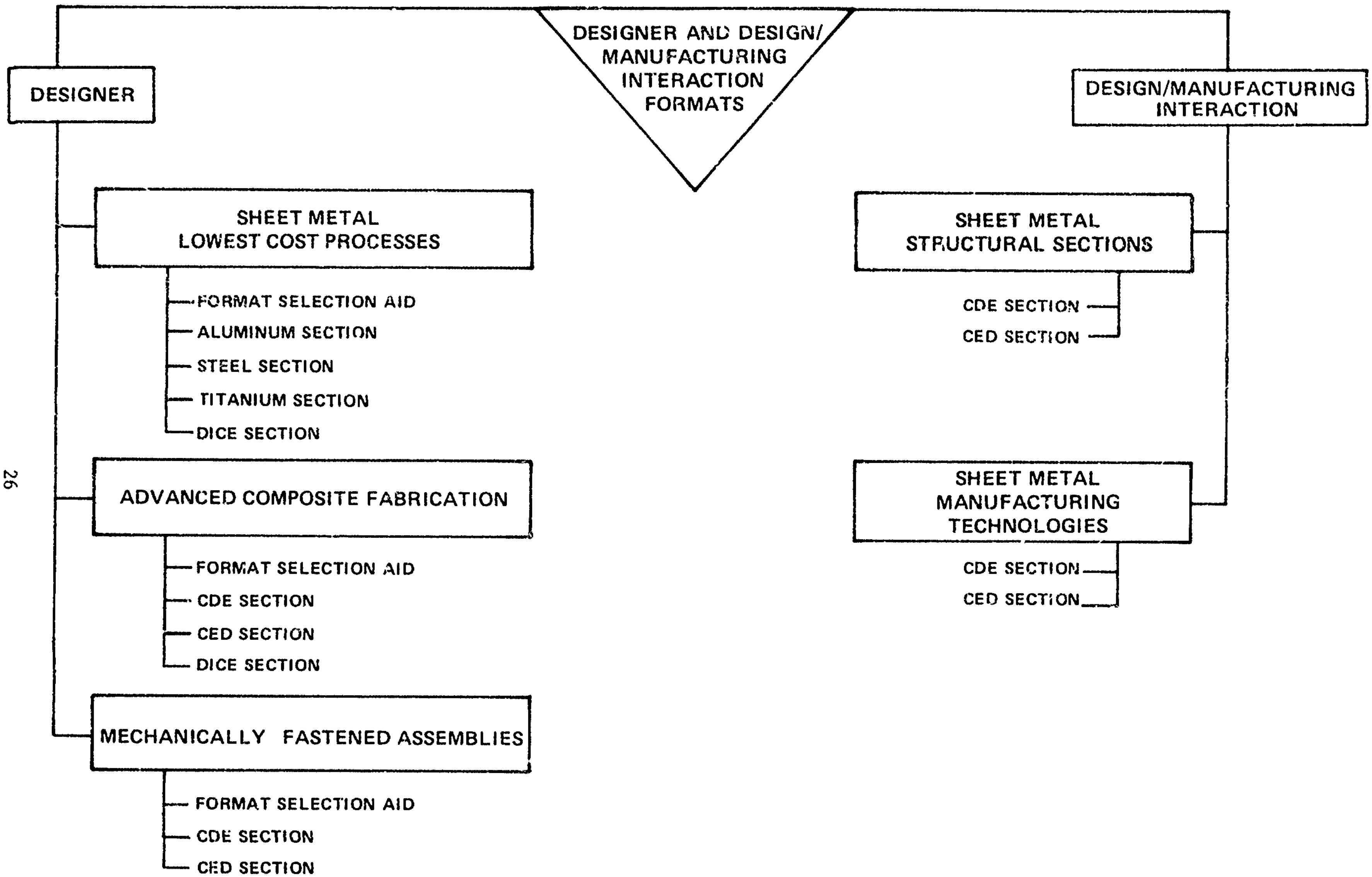

FIGURE 13. MC/DG SECTION - SELECTION AID

SECTION VI

DATA GENERATION

1. RECURRING COSTS

Throughout the MC/DG, team average production man-hours are given. Direct material costs are not included. The direct factory labor costs for manufacturing base parts and designer-influenced cost elements (DICE) were generated by the five participating aerospace companies using their own time standards, excluding personal fatigue and delay (PF&D) allowances. In developing data for recurring costs for base parts and DICE, general and detailed ground rules were formulated by the team to assure consistent results. Elements that affect the costs, such as lot release, program quantity, and learning curves, were included in the generation of data.

Direct factory labor recurring costs consist of set-up (SU) time and run time. The SU time is that time required to prepare for a production operation. The SU time is required once for each manufacturing lot of parts.

The production run time is that time required to produce a single part from the raw stock to part completion ready for storage or use in assembly. The direct factory labor time per part is obtained by dividing the SU time by the lot size, e.g., 25, as an industry average, and then adding the run time per part.

To facilitate the use of the MC/DG, the direct factory labor and man-hours per part have been adjusted to reflect the part cost in man-hours at unit 200. To achieve this, each company has applied its own proprietary learning curves. Unit 200 base part, DICE costs, and non-recurring tooling costs (NRTC) submitted by the team companies have been normalized by BCL and plotted on the various CDE and CED formats.

2. NON-RECURRING TOOLING COSTS (NRTC)

Standard tools are used, when available, to fabricate the base part and to incorporate the DICE. NRTC is documented in man-hours.

As used in the MC/DG, the NRTC includes costs of those contract tools required to make the part. Examples are forming tools, trim tools, and templates (check, drill, or router templates, etc.). The tools required to produce the tools were not included, e.g., tooling templates, tooling masters, and mock-ups. Tool material costs are included only when significant.

3. DATA COLLECTION FORMS

The manufacturing cost data (man-hours) were collected and assembled in forms such as shown in Table 1.

Part No.:
Material Type and Specification:
Material Final Condition:
Manufacturing Method:
Airframe Company Source:
Date Data Calculated:
Brief Part Description:
Part Geometry: Straight ______________ or Curved ______________, Radius ________ inches

TABLE 1. DATA COLLECTION SHEET

Lot Size	Dimensions, inches			Base Part Cost (M-H)	Non-Recurring Tooling Cost (M-H)	Designer-Influenced Cost Elements (DICE)									Discrete Part Cost (M-H)
	Length					A	B	C	D	E	F	G	H	I	
5															
10															
25															
50															

SECTION VII

SHEET-METAL AEROSPACE DISCRETE PART DEMONSTRATION SECTION

Large quantities of sheet-metal parts are used in the fabrication of airframes for both primary and secondary structures. Examples of primary structures are fuselages, bulkheads, wing boxes, ribs, and spars. Secondary structures include fairings, doors, and control surfaces. A study of sheet-metal fabrication soon reveals that new equipment approaches are required because of:

- Lack of new equipment for sheet-metal manufacture
- Little accomplished since 1940-1950 except for the bladder press and advanced stretch presses with higher tonnage.

For this reason, the Air Force has selected sheet-metal parts fabrication as the first manufacturing technology to be developed and demonstrated as an integrated computer-aided manufacturing (ICAM) system. This system will serve as a model for future integration of other manufacturing technologies for which man-hour data are also being developed for the MC/DG.

Therefore, a "Sheet-Metal Aerospace Discrete Part" MC/DG Demonstration Section was selected by the Materials Laboratory (AFWAL/MLTC). First, this will identify and quantify cost drivers in sheet-metal fabrication to indicate which operational sequences would provide high payoff opportunities for ICAM. Second, this will present cost-driver effects (CDE) and cost-estimating data (CED) using designer-oriented formats for sheet metal. These formats enable the designer to select the lowest cost manufacturing processes, develop designs avoiding or minimizing sheet-metal cost drivers, conduct structural performance/manufacturing cost trade studies, and, hence, put the designer on the lowest cost track early in the design process.

Examples of sheet-metal cost drivers follow:

- Excessive profiling for weight reduction
- Hand working due to heat treatment distortion
- Hot forming requirements (titanium)
- Lack of high-pressure forming equipment (for laminated structure, sinewave formed webs, etc.)

- Lack of standardization of clips, etc.
- Designs requiring "close fit-up" or nesting or parts.

In sheet-metal manufacture, there are two distinct types of cost drivers--those requiring added standard manufacturing operations and those introducing manufacturing complexities. This is shown below:

- Added standard manufacturing operations
  - Joggles
  - Flanged holes
  - Special lineal trim
  - Special end trim
  - Bend radii
  - Beads

  Normal Shop Operations
- Manufacturing complexities
  - Heat treatment
  - Special tolerances
  - Special finish

  Special Shop Operations

While the MC/DG serves as a cost-cutting tool for designers, examples of cost cutters in the actual manufacturing processes are as follows:

- Multi-spindle routers
  - N/C
  - Tracer
- High pressure forming equipment
  - Over 30,000 psi
  - Large bed
- Heat treatment
  - Cryogenic
  - Spray quenching
  - Glycol quenching
- Titanium routing equipment
  - Laser
- Improved hot forming technology
- Automated heat treatment/processing.

The Materials Laboratories' Computer-Aided Manufacturing (CAM) Architecture--Task 3, "Sheet-Metal Fabrication Technology Program", conducted by Boeing Military Airplane Development Company, Report No. IR-765-6(1), revealed that of the material distribution in a typical transport aircraft, about 88 percent of the parts were in aluminum with stainless steel representing approximately 9 percent, and titanium approximately 3 percent. It was further found that the part configurations displayed the following distribution:

Material	Flat	Formed
Aluminum	43.2%	56.8%
Titanium	46.3%	53.7%
Stainless Steel	47.2%	52.8%
Nickel Alloys	28.1%	71.9%

Further important distributions in the Boeing report are.

Distribution by Forming Method for Aluminum Parts

Method	Percentage
Brake Form	71.4
Hydro Form	17.1
Die Form	6.0
Stretch Form	1.7
Roll Form	1.3
Hammer Form	1.1
Joggle Form	1.0
Other Methods	0.4

Distribution by Forming Method for Titanium Parts

Method	Percentage
Brake Form	46.6
Hydro Form	29.7
Die Form	17.0
Roll Form	2.7
Hot Form	2.6
Joggle Form	1.4

Distribution by Forming Method for Stainless Steel Parts

Method	Percentage
Brake Form	59.4
Die Form	35.5
Roll Rom	3.6
Other	1.5

Distribution of Part Quantities and Direct Labor Hours for Major Forming Processes

Process	Part Quantity, Percentage	Labor Hour, Percentage
Brake Form	71.1	47.0
Hydro Form	15.8	23.6
Die Form	7.6	4.6
Stretch Form	1.6	10.0
Roll Form	1.4	6.0
Hammer Form	1.1	5.5
Joggle Form	1.0	2.6
Impact Form	0.2	0.4
Spin Form	0.2	0.4

Distribution by Shape

Shape	Percentage
One Bend	39.5
Two or More Parallel Bends, One Direction	15.5
Two or More Non-Parallel Bends, One Direction	14.5
Two or More Parallel Bends, Two Directions	12.9
Two or More Non-Parallel Bends, Two Directions	9.5
Curved Bend Line	7.1
Miscellaneous	1.0

The above information served to support and confirm the MC/DG coalition-derived ground rules, part sketches, and manufacturing methods in the development of the MC/DG "Sheet-Metal Aerospace Discrete Part" Demonstration Section.

The ground rules for sheet-metal discrete parts are included in Appendices A and B. It will be noted that man-hours on the formats relate to lot size 25. Examples of the impact of lot size for three different sheet-metal discrete parts and in three materials are shown in Figures 14 to 17. The lot size of 25 was selected as it:

- Represents an optimum production release size; hence, reduces manufacturing cost
- Represents aerospace industry consensus of most common release size
- Is frequently used in aerospace cost estimating
- Keeps the effect of set-up on discrete part cost in the proper perspective
- Maximizes operator efficiency
- Provides improved opportunity for learning curve improvements.

1. SHEET-METAL DISCRETE PART SELECTION

The discrete parts for which manufacturing man-hours were developed for the candidate manufacturing technologies were selected as being representative of typical airframe components in production. The manufacturing man-hours were determined for all operational sequences necessary to the identification and protection (packaging) sequences of the parts prior to assembly. Dimensioned sketches of each component were prepared by the team. The part sketches were produced at the team meetings and examples of the sketches are included in Appendix B.

It was essential to establish certain definitions prior to development of the manufacturing man-hour data. Important definitions are as follows:

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as heat treatment, cut-outs, and joggles.

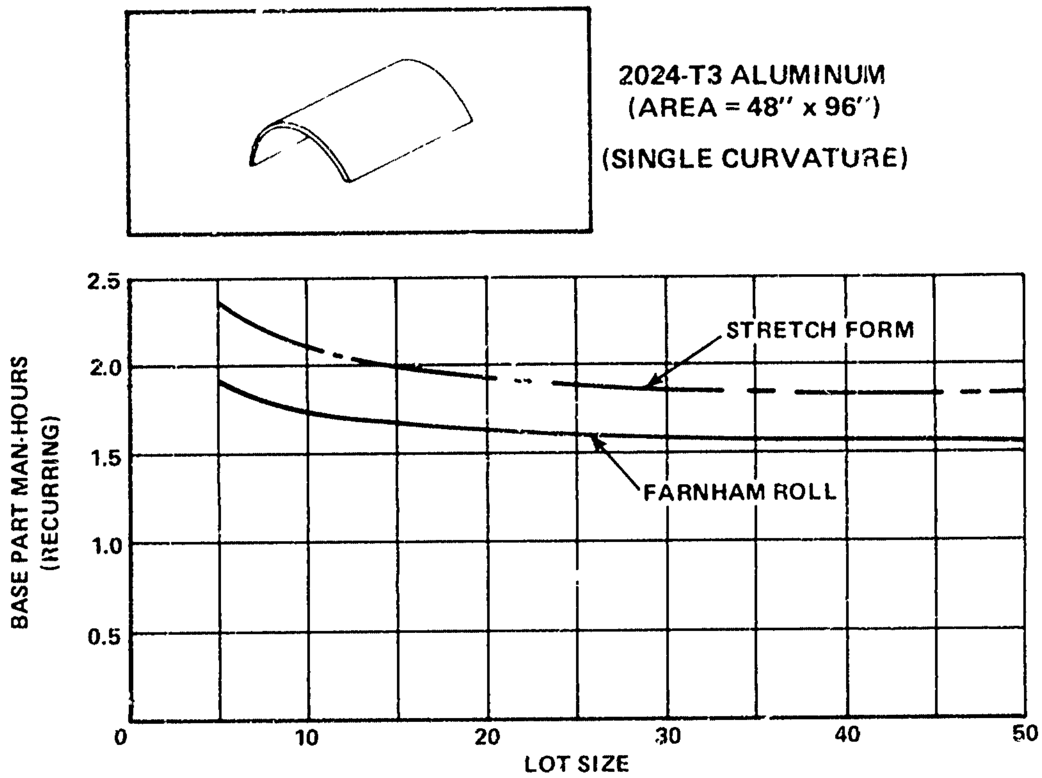

FIGURE 14. COST EFFECT OF LOT SIZE - SKIN PANEL

LS—1

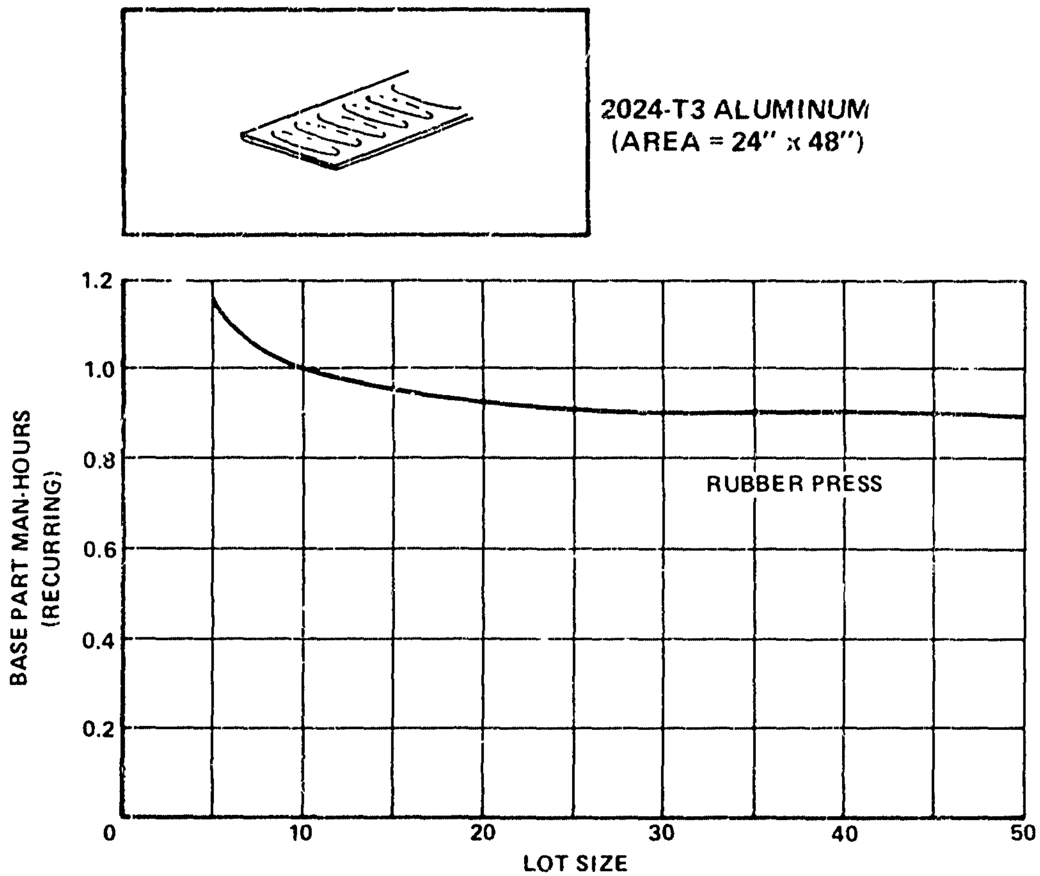

FIGURE 15. COST EFFECT OF LOT SIZE - BEADED PANEL

LS—2

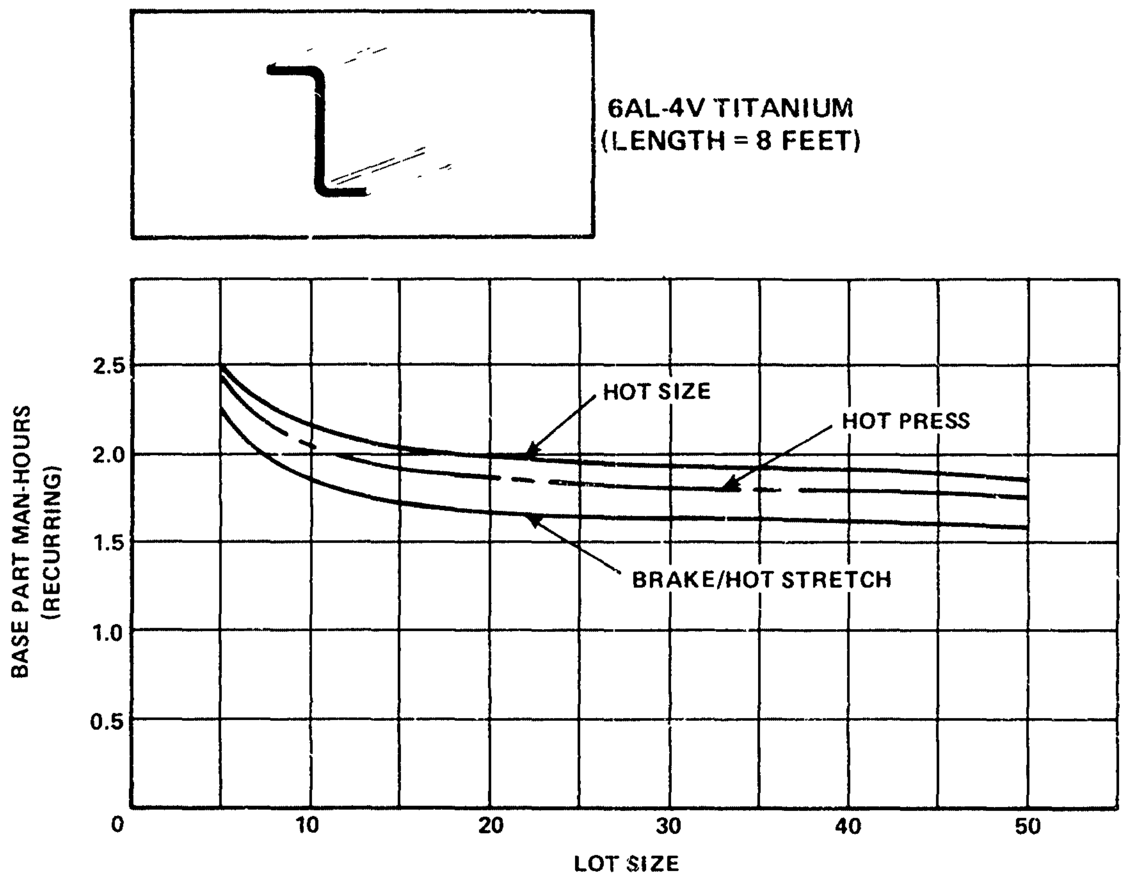

FIGURE 16. COST EFFECT OF LOT SIZE - CURVED LINEAI SHAPE

LS—3

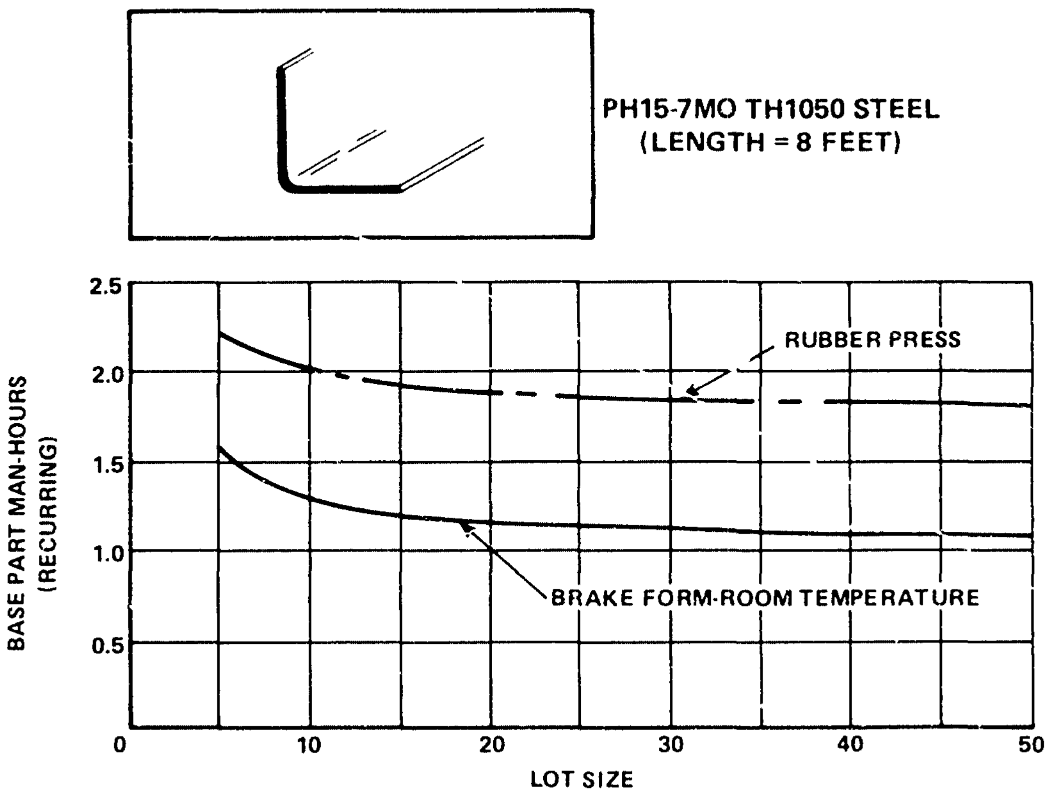

FIGURE 17. COST EFFECT OF LOT SIZE - STRAIGHT LINEAL SHAPE

LS—4

(2) Designer-Influenced Cost Elements (DICE): Includes joggles, cut-outs, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

There are basically two distinct types of DICE--those that require added standard manufacturing operations and those which introduce manufacturing complexities requiring special shop operations.

The utilization of the base part, DICE, and discrete part approach in making comparisons between manufacturing methods and also conducting cost comparisons between equivalent structural sections is illustrated in Figures 18, 19, and 20. It will be noted in Figure 18 that the comparison is first made between various panels reinforced by different lineal shapes such as stiffeners or stringers. In the case of panels, flat, flanged, single contour, and compound contour base parts are shown with the DICE consisting of beads, lightening holes, cut-outs, special trim, and heat treatment. The base part lineal shapes consist of straight and single contour configurations. Examples of the DICE for these lineal shapes are joggles, lightening holes, special trim, and heat treatment. The objective is to determine the cost (man-hours) of the sheet-metal forming methods, the additional processes that may be required for the DICE, the tooling, and eventually the cost of utilizing any emerging manufacturing technologies.

The integration of the panels and lineal shapes into structural assemblies, such as lifting surfaces, fuselages, and internal webs, is shown in Figure 19.

Utilizing, firstly, the "Sheet-Metal Aerospace Discrete Part Demonstration Section" and the "Mechanically Fastened Assembly Demonstration Section", a comparison between the manufacturing cost for different structural assembly configurations can be determined for the candidate forming methods, additional processes required for DICE, and tooling. The next step is to conduct structural performance/

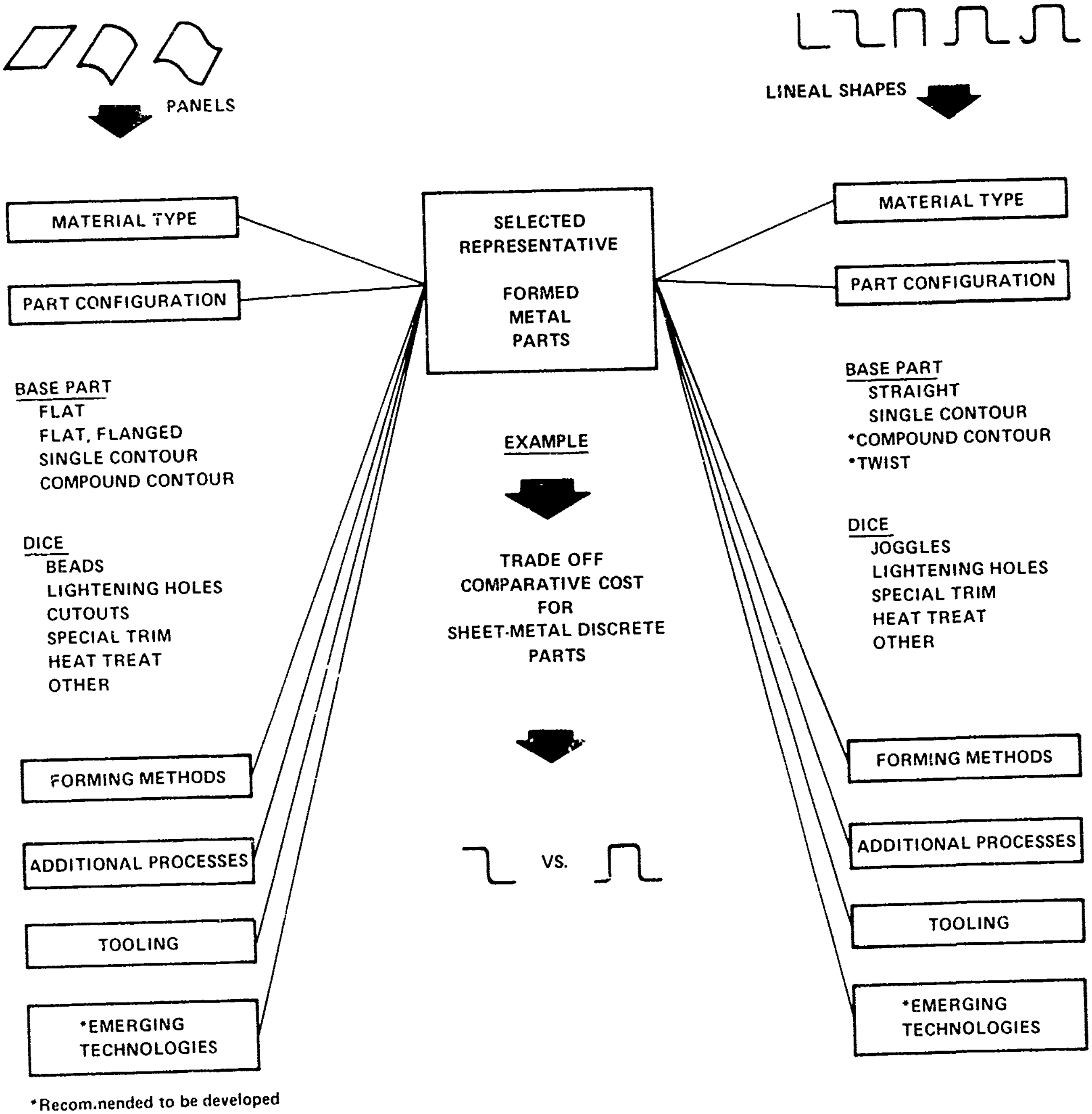

FIGURE 18. UTILIZATION OF SHEET-METAL AEROSPACE DISCRETE PART DEMONSTRATION SECTION

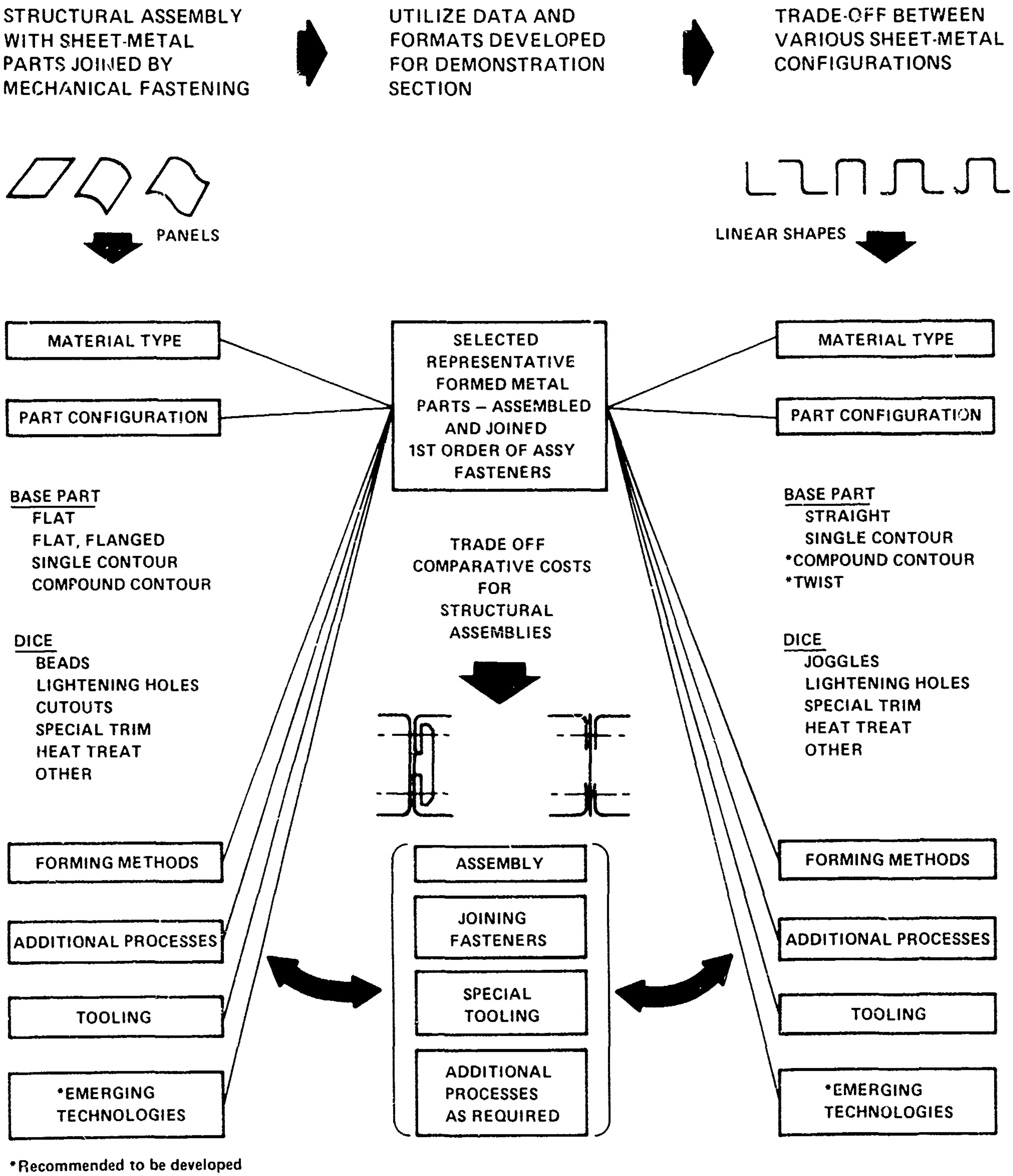

FIGURE 19. UTILIZATION OF SHEET-METAL AEROSPACE DISCRETE PART AND MECHANICALLY FASTENED ASSEMBLIES DEMONSTRATION SECTIONS

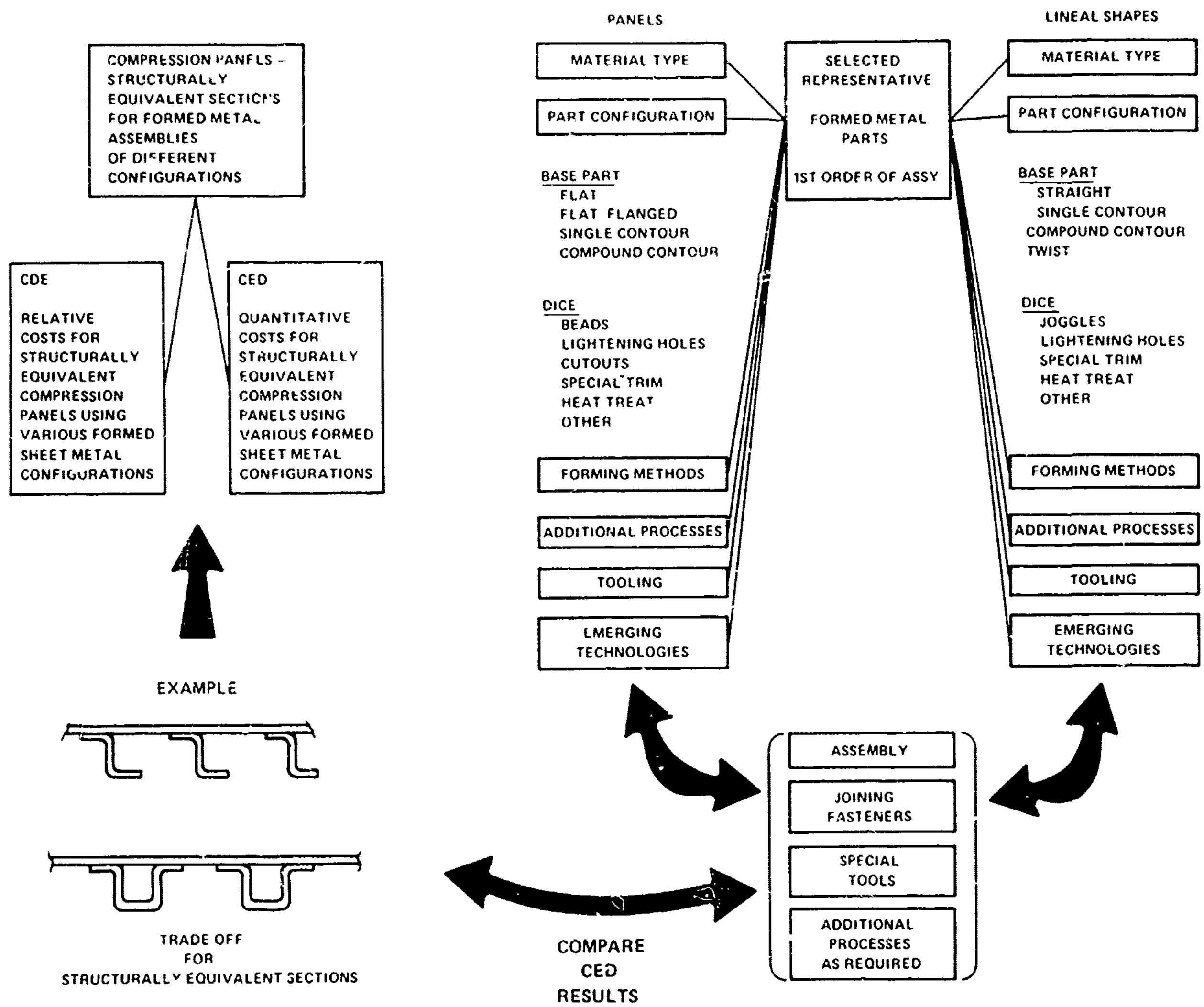

FIGURE 20. UTILIZATION OF SHEET-METAL AEROSPACE DISCRETE PART DEMONSTRATION SECTION IN STRUCTURAL PERFROMANCE/ MANUFACTURING COST TRADE-STUDY

manufacturing cost comparisons between the candidate structural configurations consisting of panels of various configurations with the stiffening lineal shapes. The approach for a typical trade study, in which cost effectiveness criteria (dollars/lb) and manufacturing costs are compared, is shown in Figure 20. This approach has been utilized in the trade studies on fuselage panels discussed later.

The results of a typical structural weight/manufacturing cost trade study is shown in Figure 21. This is for a titanium fuselage panel and seven structural concepts were evaluated. It will be noted that the cost of Concept VII is $1992, but that the weight of this panel is 87.79 lbs. However, the recommended concept costs $2680 and that the weight of this panel is 58.46 lbs. The cost per pound weight saved is $23, which is the lowest cost of the seven concepts evaluated.

2. MANUFACTURING TECHNOLOGIES ANALYZED FOR SHEET METAL PARTS

The following manufacturing technologies were analyzed for aluminum, titanium, and steel, respectively:

<u>Aluminum</u>

Brake/Buffalo Roll
Brake Form
Brake/Stretch
Die Form
Drop Hammer
Farnham Roll
Rout (Flat Sheet)
Rubber (Hydro) Press
Stretch Form

<u>Titanium</u>

Brake Form (Room Temperature)
Brake (Room Temperature)/Hot Stretch
Creep Form
Farnham Roll
Hot Press
Preform/Hot Size

CONCEPT	COST		WEIGHT		COST OF WEIGHT SAVED– $/LB
	$/PANEL	Δ$/PANEL	LBS/PANEL	ΔWT LBS	
I	2986	994	59.02	-28.77	35
II	2680	688	58.46	-29.33	23
III	4473	2481	58.26	-29.53	84
IV	3915	1923	57.58	-30.21	64
V	4401	2499	64.48	-23.31	107
VI	3933	1941	63.80	-23.99	81
VII	1992	BASE	87.79	BASE	BASE

RECOMMENDED CONCEPT

FIGURE 21. COST-WEIGHT TRADE-OFF SUMMARY FOR TITANIUM FUSELAGE PANEL CONCEPTS

Steel

Brake/Buffalo Roll

Brake Form (Room Temperature)

Brake/Stretch

Farnham Roll

Rubber Press

Stretch Form

The MC/DG team has specified operational sequences on informational sheets for each of the manufacturing technologies studied for the aerospace discrete parts manufactured in both metallic and non-metallic materials including mechanically fastened assemblies. This is an essential step in the man-hour development tasks in order to minimize possible variations between team members so that a realistic industry average is achieved for subsequent insertion on the MC/DG formats. Examples of the operational sequences are shown below. These are for an aluminum beaded panel, titanium straight, and steel curved stringers.

Aluminum Beaded Panel

Initial Material Condition: 2024-0 (annealed)

Final Condition: 2024-T62

Manufacturing Method: Rubber (Hydro) Press Forming

1. Shear (length to width)
2. Stack drill (tooling holes)
3. Deburr
4. Polish radii areas
5. Degrease
6. Rubber (Hydro) press form
7. Hand finish form
8. Identify (metal tabs)
9. Degrease
10. Solution heat-treat to T-42
11. Ice box
12. Check and straighten
13. Rout periphery

14. Deburr
15. Degrease
16. Age to T-62
17. Alodine
18. Prime
19. Identify (rubber stamp)
20. Protect (package).

Titanium Straight Lineal Angle

Material type: 6Al-4V

Manufacturing Method: Brake Form/Hot Joggle

1. Shear (length and width)
2. Machine lineal and end trim
3. Brake form (one bend)
4. Hot joggle (two joggles)
5. Identify (metal tag)
6. Alkaline clean
7. Descale
8. Alkaline clean
9. Surface preparation (dry hone)
10. Prime
11. Identify (rubber stamp)
12. Protect (package).

Steel Curved Lineal Angle

Material type: Ph15-7Mo Cres.

Manufacturing Method: Brake and Stretch Form

1. Shear (length and width)
2. Deburr
3. Degrease
4. Brake (one bend)
5. Stretch Form
6. Joggle
7. Identify (metal tag)
8. Transform at 1400°F
9. Check and straighten
10. Age to TH1050
11. Descale
12. Deburr
13. Trim length
14. Trim edges
15. Deburr
16. Clean and passivate
17. Identify (rubber stamp)
18. Protect (package).

SHEET-METAL AEROSPACE DISCRETE PART

DEMONSTRATION SECTION

SHEET-METAL AEROSPACE DISCRETE PART DEMONSTRATION SECTION

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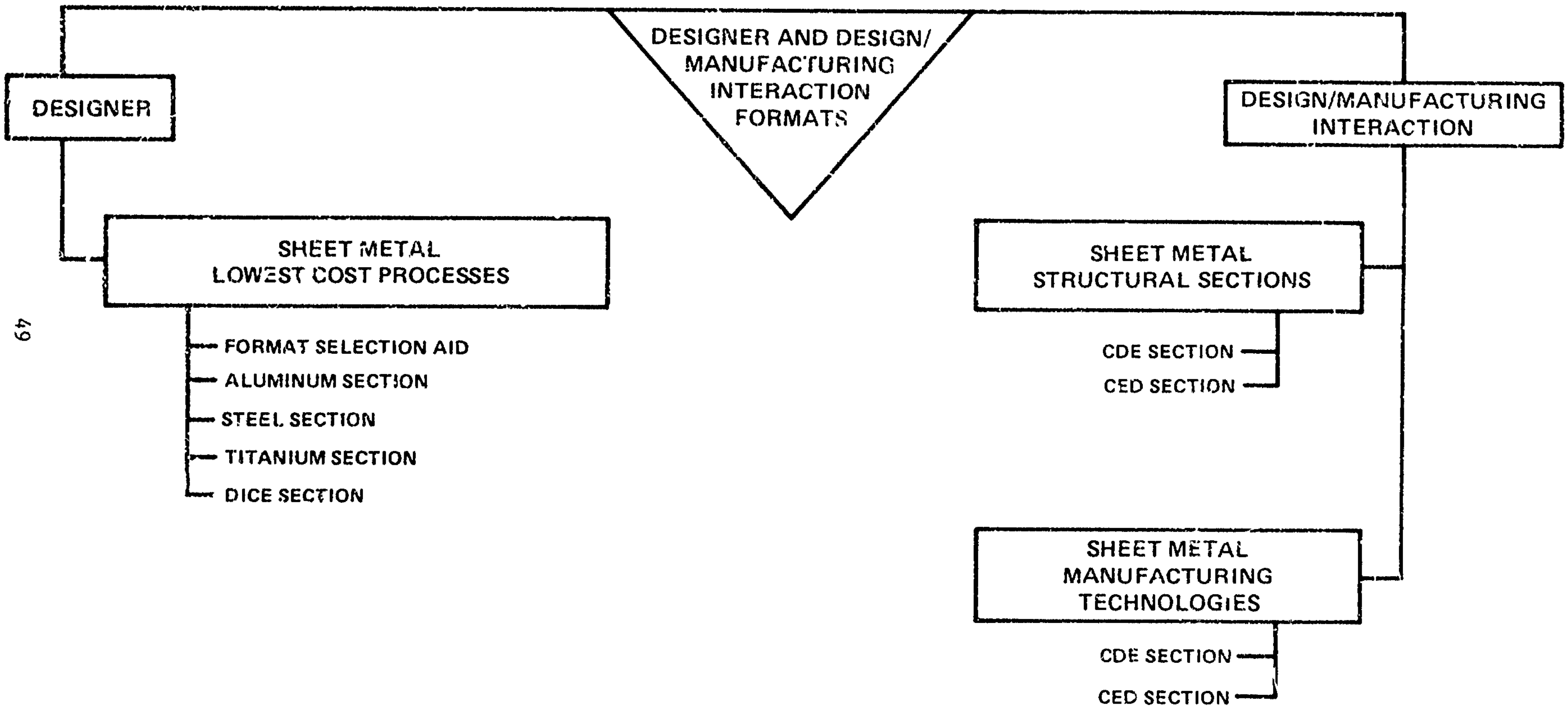
"MANUFACTURING COST/DESIGN GUIDE (MC/DG)"

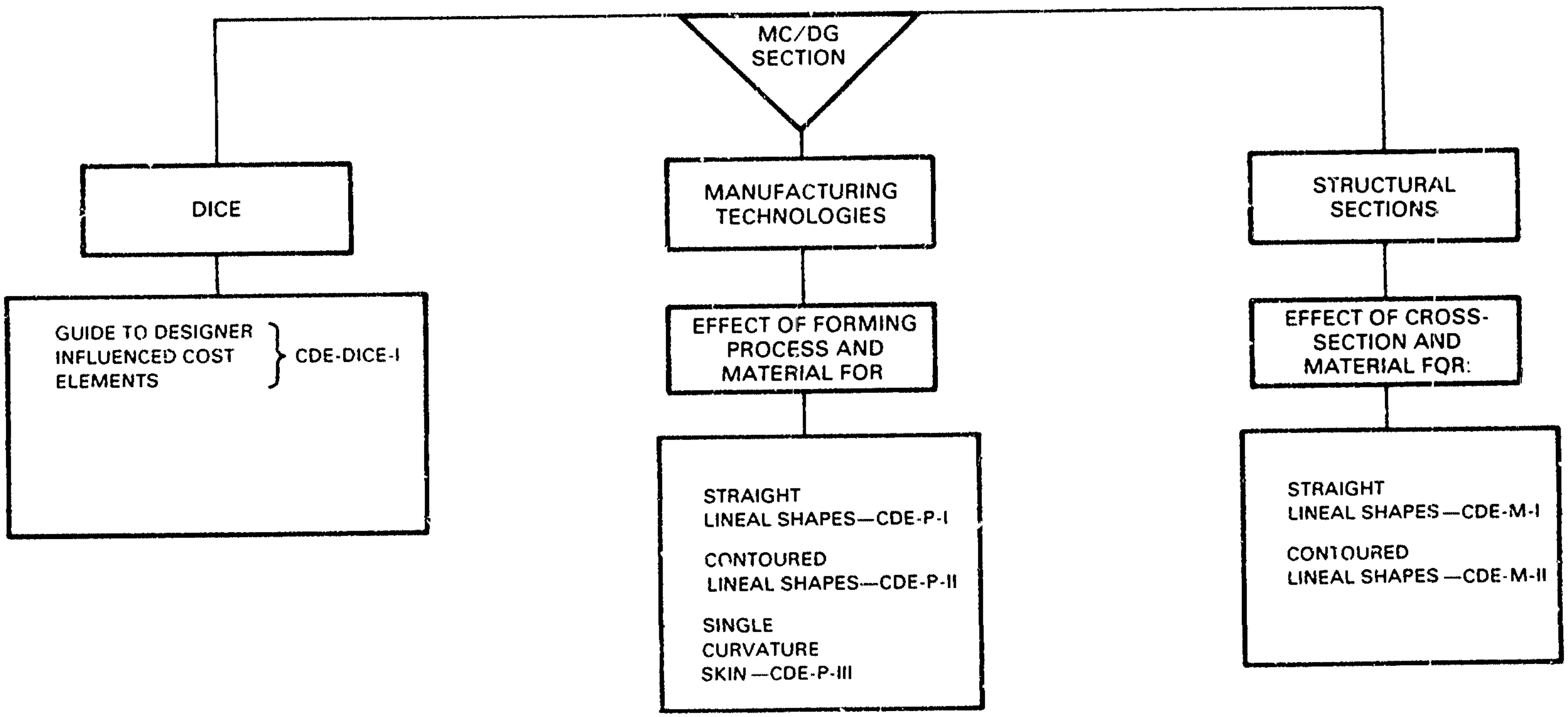
MC/DG SECTION -- SELECTION AID



"MANUFACTURING COST/DESIGN GUIDE (MC/DG)"

FORMAT SELECTION AID

SHEET-METAL COST-DRIVER EFFECT (CDE) DATA



"MANUFACTURING COST/DESIGN GUIDE (MC/D

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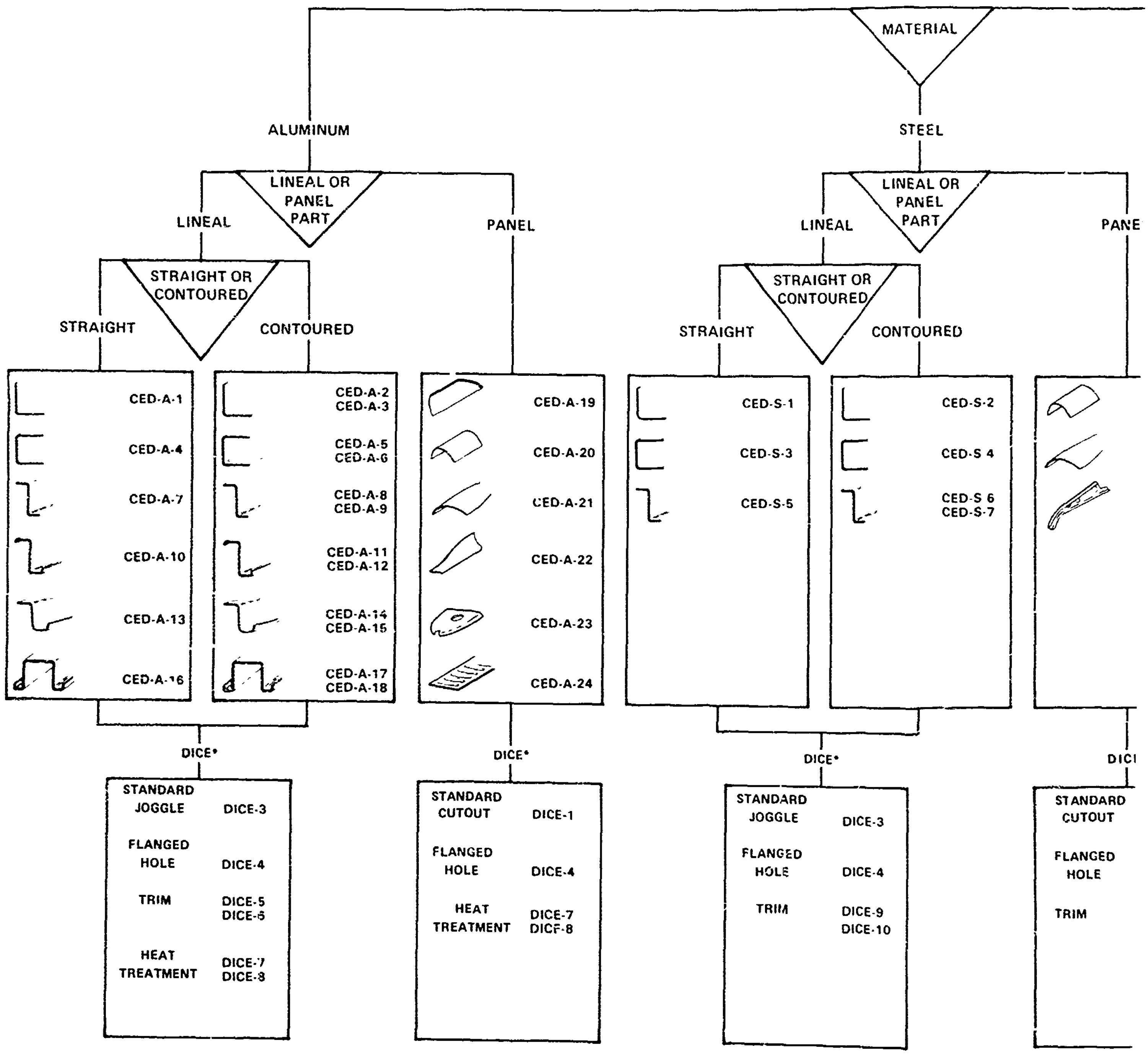
LOWEST COST PROCESSES

COST-ESTIMATING DATA (CED)



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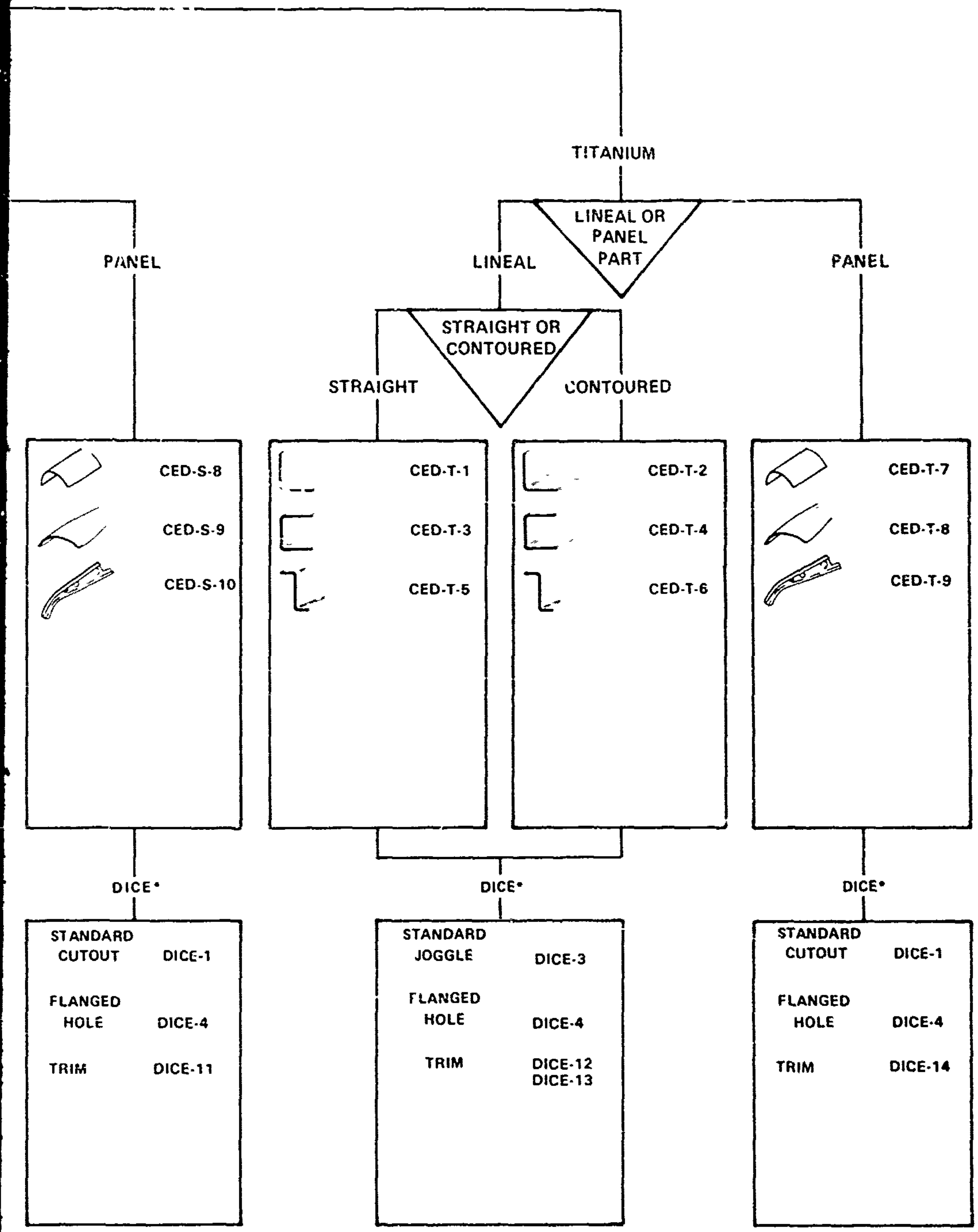

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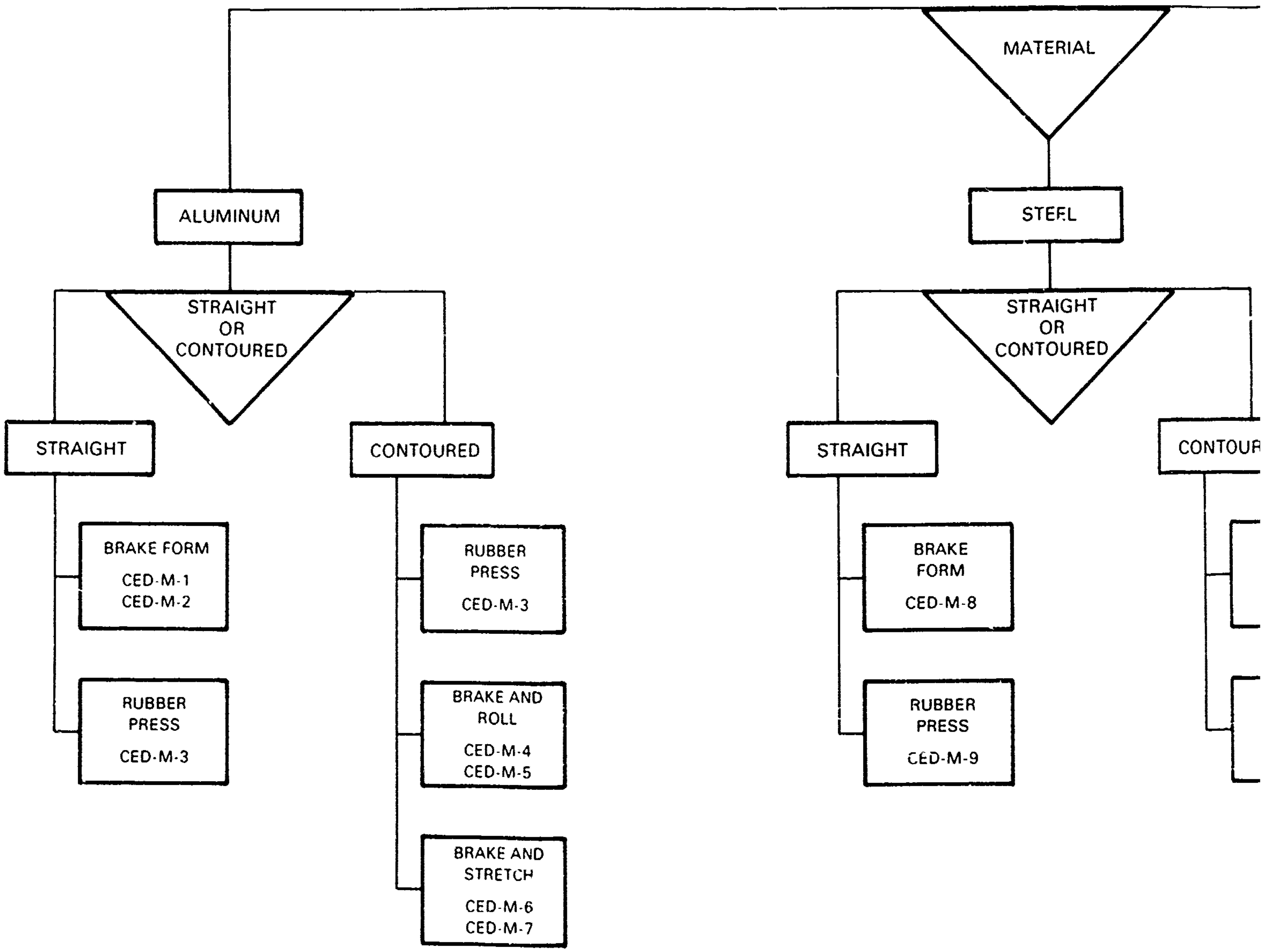
"MANUFACTURING COST/DESIGN GUIDE (MC

FORMAT SELECTION AI

COMPARISON OF SHEET-METAL STRUCTURA
PRODUCED BY SAME MANUFACTURING

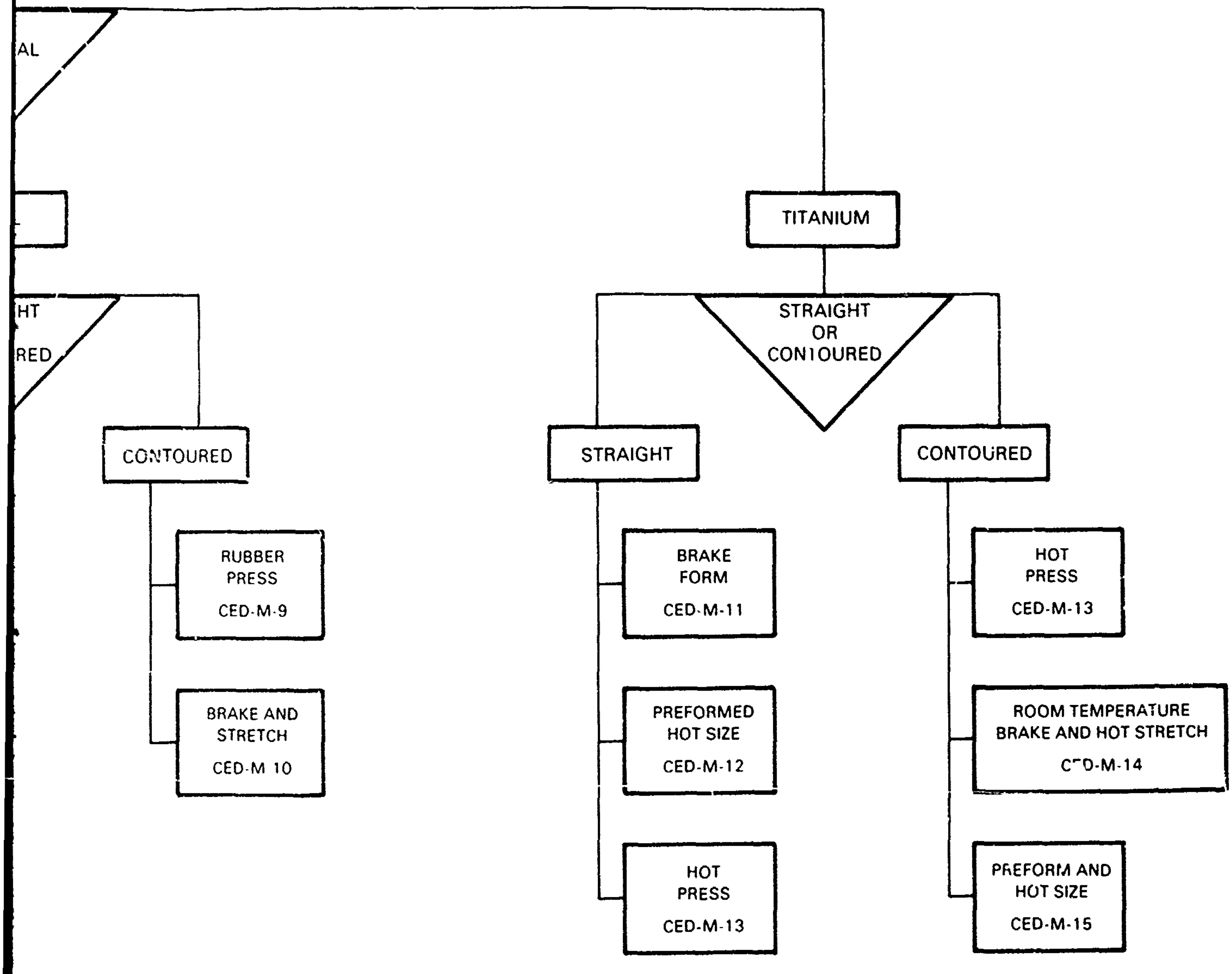


ESIGN GUIDE (MC DG)

ECTION AID

AL STRUCTURAL SECTIONS

UFACTURING METHOD



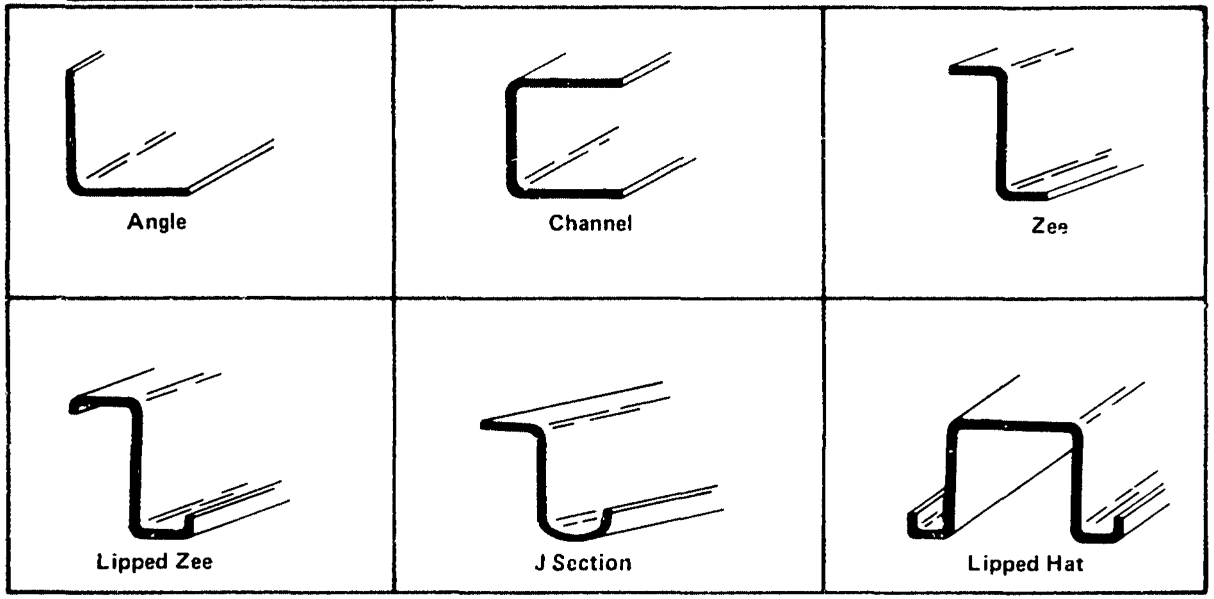
SHEET-METAL AEROSPACE DISCRETE PARTS

BASE PARTS ANALYZED

SHEET METAL AEROSPACE BASE PARTS

1. ALUMINUM

STIFFENERS AND STRINGERS



Part Lengths

24" to 144"

Manufacturing Methods

Straight Parts

- Brake Form
- Rubber Press

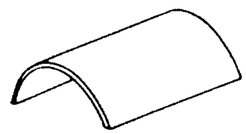
Contoured Parts

- Brake/Buffalo Roll
- Brake/Stretch
- Rubber Press

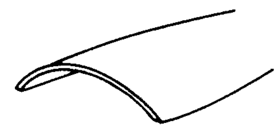
SHEET METAL AEROSPACE BASE PARTS

1. ALUMINUM

SKIN PANELS



Cylindrical Contour



Compound Contour

Panel Sizes

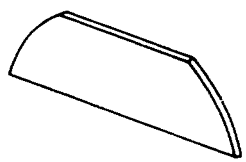
12" x 48" to 48" x 144"

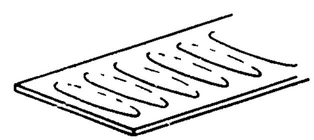
Manufacturing Methods

Cylindrical Contour:
- Farnham Roll
- Stretch Form

Compound Contour:
- Stretch Form

WEBS AND DOUBLERS





Part Sizes

12" x 24" to 48" x 240"

8" x 24" to 36" x 144"

Manufacturing Methods

- Routing

- Rubber Press

Sheet Metal Aerospace Base Parts

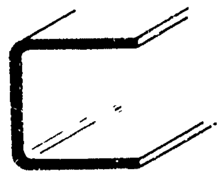
1. ALUMINUM

RIBS (TYPICAL)

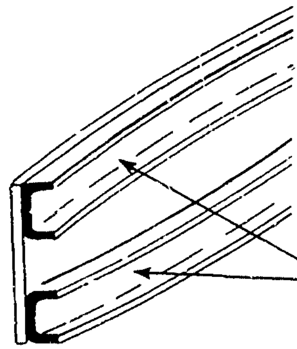
10″ x 4″ to 30″ x 12″

Manufacturing Methods

- Die Form
- Rubber Press



Part Sizes



Length: 24″ to 144″

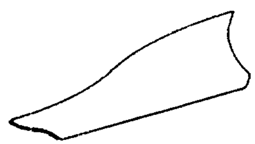
Straight

- Brake Form
- Rubber Press

Contoured

- Brake/Buffalo Roll
- Brake/Stretch
- Rubber Press

FAIRINGS AND CLOSURES



Part Sizes

12″ x 12″ to 36″ x 72″

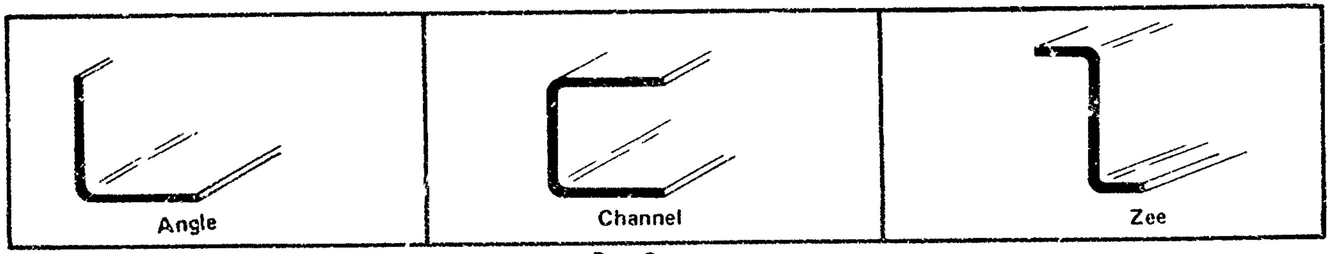
Manufacturing Methods

- Drop Hammer

Sheet Metal Aerospace Base Parts

2. TITANIUM

STIFFENERS AND STRINGERS



Part Size

Length: 24" to 144"

Manufacturing Methods

Straight Parts

- Brake Form – Room Temperature
- Preform/Hot Size
- Hot Press

Contoured Parts

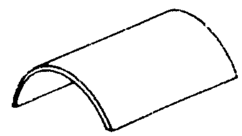
- Brake Form – Room Temperature and Hot Stretch
- Preform/Hot Size
- Hot Press

Sheet Metal Aerospace Base Parts

2. TITANIUM

SKIN PANELS

Cylindrical Contour



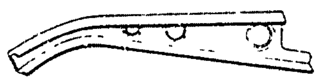
Panel Sizes

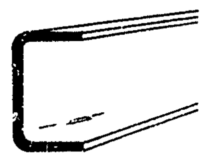
24" x 48" to 48" x 96"

Manufacturing Methods

- Creep Form
- Farnham Roll
- Hot Size
- Brake Form

RIBS AND FRAMES (TYPICAL)





Part Sizes

4" x 12" to 18" x 72"

Length: 24" to 144"

Manufacturing Methods

- Preform/Hot Size
- Hot Press

Straight

- Brake Form – Room Temperature
- Preform/Hot Size
- Hot Press

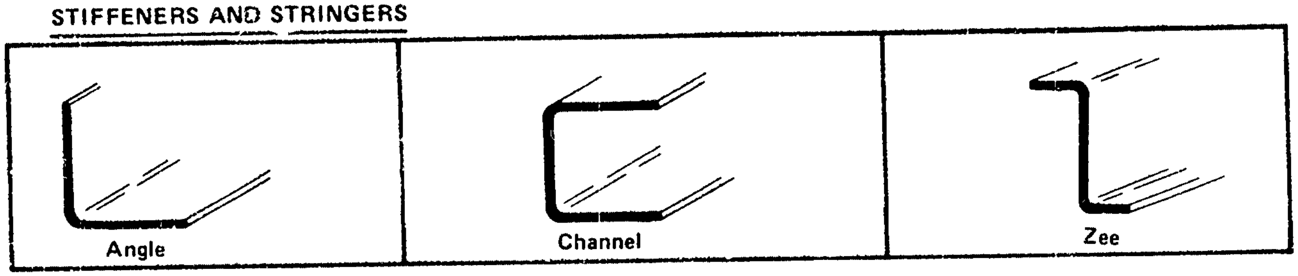
Contoured

- Brake Form – Room Temperature and Hot Stretch
- Preform/Hot Size
- Hot Press

Sheet Metal Aerospace Base Parts

3. STEEL

STIFFENERS AND STRINGERS



Part Sizes

Length: 24″ to 144″

Manufacturing Methods

Straight Parts	Contoured Parts
• Brake Form	• Brake/Stretch
• Rubber Press	• Rubber Press

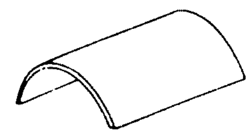
Note: All forming carried out at room temperature.

Sheet Metal Aerospace Base Parts

3. STEEL

SKIN PANELS

Cylindrical Contour



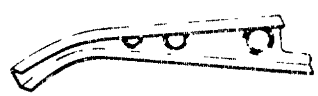
Panel Sizes

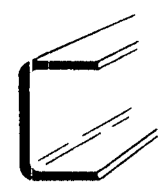
24″ x 48″ to 48″ x 96″

Manufacturing Methods

- Stretch Form
- Farnham Roll
- Brake Form

RIBS AND FRAMES (TYPICAL)





Part Sizes

4″ x 12″ to 18″ x 72″

Length: 24″ to 144″

Manufacturing Methods

- Rubber Press

Straight

- Brake Form
- Rubber Press

Contoured

- Brake/Stretch
- Rubber Press

Note: All forming carried out at room temperature.

SHEET-METAL AEROSPACE DISCRETE PART
DEMONSTRATION SECTION

TABLE 2. DESIGNER-INFLUENCED COST ELEMENTS (DICE)

Designation on Formats	Sheet-Metal DICE
A	Heat Treatment
B	Standard Joggle
C	Standard Flanged Hole
D	Trim After Forming
E	Panel Cut-out
F	Trim Prior to Forming

SHEET-METAL AEROSPACE DISCRETE PARTS
MANUFACTURING TECHNOLOGIES ANALYZED

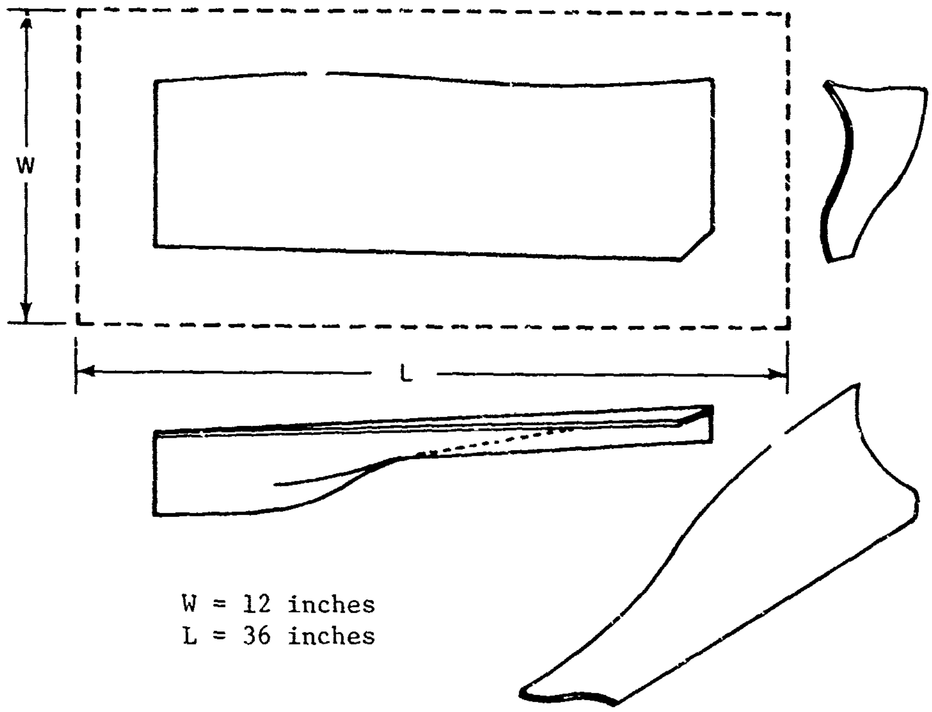
TABLE 3. MANUFACTURING PROCESSES EVALUATED IN "SHEET METAL AEROSPACE DISCRETE PART" DEMONSTRATION SECTION

Aluminum
Brake/Buffalo Roll
Brake Form
Brake/Stretch
Die Form
Drop Hammer
Farnham Roll
Rout (Flat Sheet)
Rubber (Hydro) Press
Stretch Form
Titanium
Brake Form (Room Temperature)
Brake (Room Temperature)/Hot Stretch
Creep Form
Farnham Roll
Hot Press
Preform/Hot Size
Steel
Brake/Buffalo Roll
Brake Form (Room Temperature)
Brake/Stretch
Farnham Roll
Rubber Press
Stretch Form

EXAMPLES OF UTILIZATION OF "SHEET METAL
AEROSPACE DISCRETE PART"
DEMONSTRATION SECTION

1. EXAMPLE. ALUMINUM FAIRING

Problem: Determine manufacturing cost (man-hours) of an aluminum (2024) fairing of dimensions: 36" x 12"; see sketch below.



W = 12 inches
L = 36 inches

(1) Utilize Format Selection Aid for Sheet-Metal.

(2) Determine format to use. In this case, Format CED-A-22 is required.

(3) Study format determining parameters and conditions necessary for its use; relate to part. For CED-A-22 area (ft^2) is needed. The dimensions of the part are given as 36" x 12"; i.e., 3 ft^2.

(4) From CED-A-22, read values for the recurring cost and non-recurring tooling cost (NRTC):

- Recurring cost at unit 200 = 0 71 man-hours per part
- NRTC = 275 man-hours for 200 parts or 275/200 = 1.375 man-hours per part
- Learning curve factor to convert unit cost at 200 to cumulative average cost for a 90% curve and a quantity of 200: 0.5248/0.4469 = 1.17 (see table below)

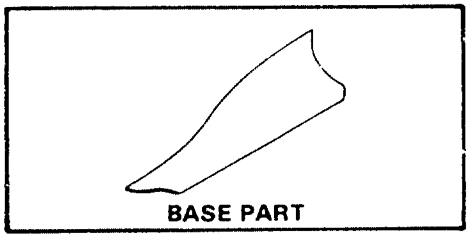
The base part manufacturing cost is thus 0.71 (1.17) + 1.38 = 2.21 man-hours per part.

(5) Check for applicable Designer-Influenced Cost Elements (DICE). Format indicates that no DICE are applicable for the drop hammer manufacturing method for producing part. This implies that the base part cost calculated (4 above) is the final total manufacturing cost for the discrete part (excluding direct material cost).

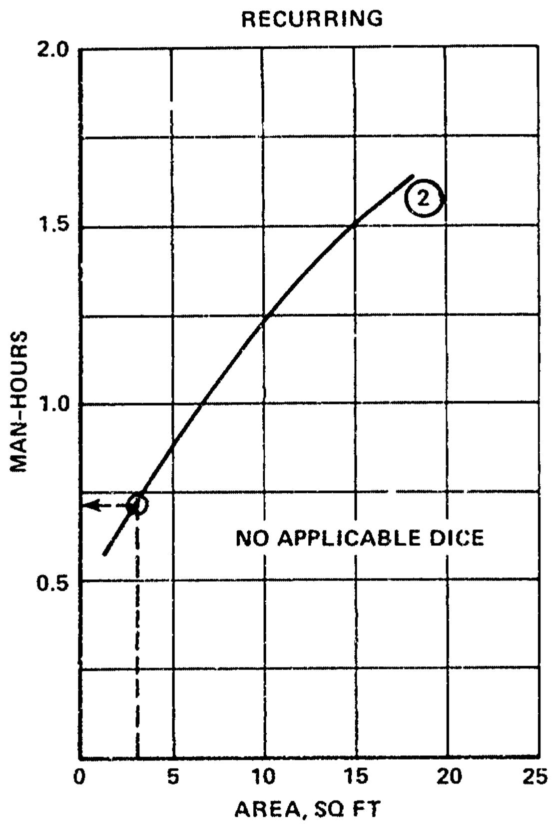
To obtain the cost (dollars), multiply 2.21 man-hours by the labor rate applicable at company. If material cost could be a factor, for example, if this fairing were being compared with a fiberglass fairing, material cost would be added to the manufacturing cost.

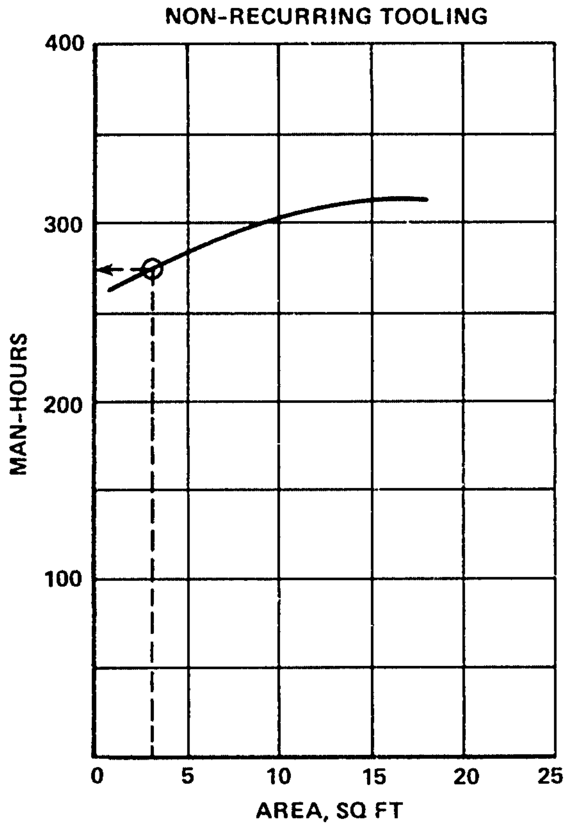
Factors to convert the MC/DG 200th unit cost to the cumulative average cost for the design quantity and learning curve involved.

Design Quantity	LEARNING CURVE ~ %						
	95	90	85	80	75	70	65
1	1.48	2.25	3.48	5.50	9.00	15.00	27.00
10	1.33	1.79	2.47	3.48	5.04	7.53	11.67
25	1.25	1.59	2.05	2.71	3.68	5.13	7.43
50	1.19	1.44	1.79	2.22	2.85	3.76	5.14
100	1.13	1.30	1.52	1.80	2.18	2.73	3.51
200	1.08	1.17	1.30	1.45	1.66	1.95	2.36
350	1.04	1.08	1.14	1.22	1.33	1.48	1.70
500	1.01	1.02	1.05	1.09	1.15	1.24	1.38
750	.98	.96	.96	.96	.97	1.01	1.09
1000	.96	.92	.89	.87	.87	.88	.91



ALUMINUM FAIRING, LOWEST COST PROCESS DROP HAMMER (INCLUDES PROCESS AND TRIM)



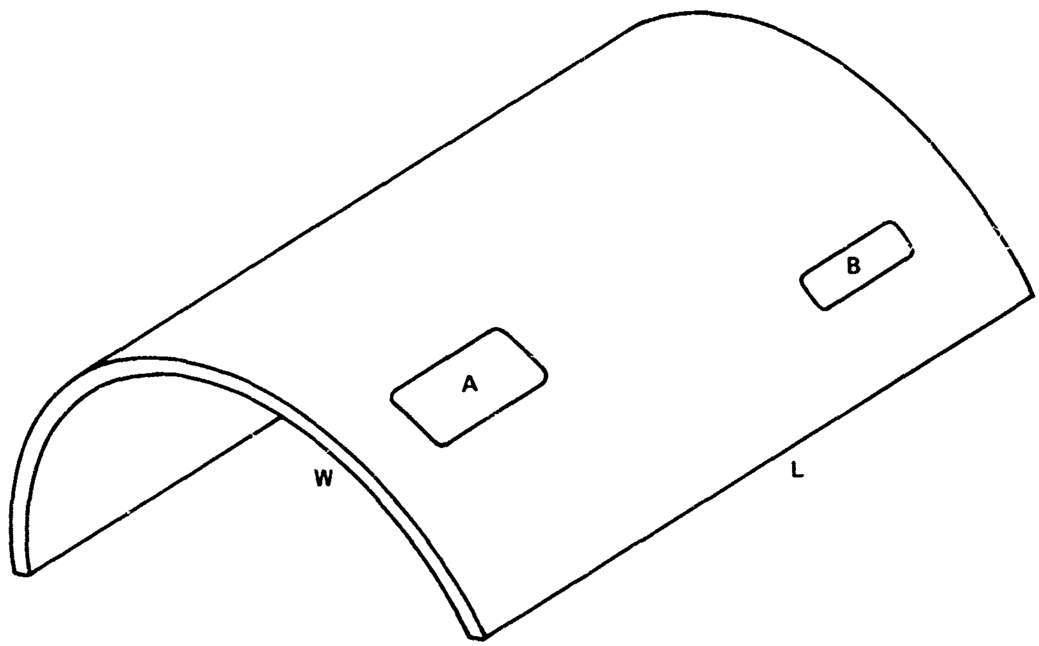


(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62

CED—A-22

2. EXAMPLE. STEEL SKIN

Problem: Determine manufacturing cost (man-hours) of a PH15-7Mo steel skin, having circular curvature and two cut-outs; see sketch below:



Dimensions:

- Sheet developed size: 60" (length)
  36" (width)
- Cut-outs: A: 12"x6"
  B: 4"x8"

(1) Utilize Format Selection Aid for Sheet Metal

(2) Determine formats to use. In this case, Formats CED-S-8 for skin and DICE-1 for cut-outs.

(3) Study formats determining parameters and conditions necessary for their use. In this case, area required, in square feet, i.e., 15 ft^2.

(4) Determine base part recurring and non-recurring tooling costs (man-hours):

- Recurring cost at unit 200 = 1.55 man-hours per part
- NRTC = 74 man-hours for 200 parts = 0.37 man-hours per part
- Learning curve factor = 1.17 (See Example 1, page 68).

Therefore, base part manufacturing cost is: 1.55 (1.17) + 0.37 = 2.18 man-hours.

(5) Analyze manufacturing cost for Designer-Influenced Cost Elements (DICE). For this discrete part, cut-outs (DICE-E) are called out on drawing. Format CED-S-8 indicates that DICE-E is applicable for the Farnham Roll manufacturing method. Therefore, Format DICE-1 is required to determine the manufacturing cost of the cut-outs.

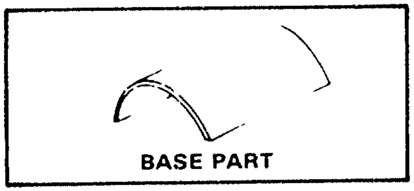
DICE-1 indicates that a standard cut-out requires 0.036 man-hours per foot of perimeter, i.e.,

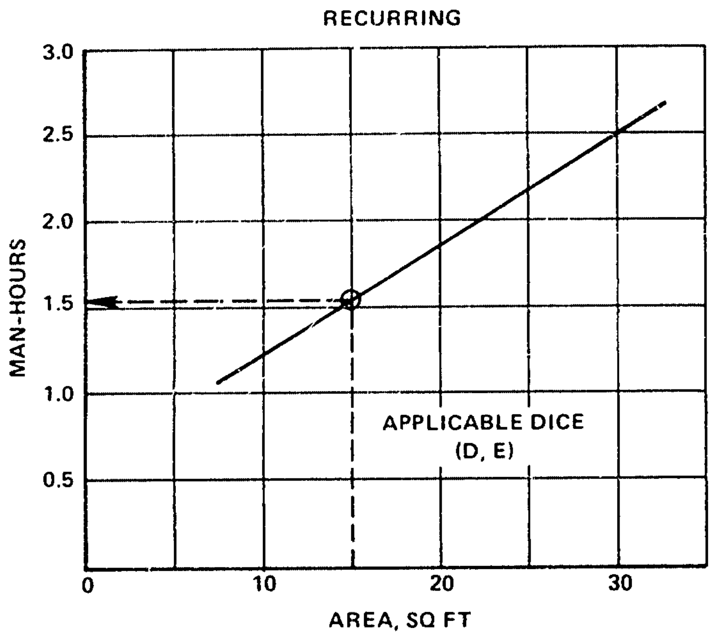
- 2 feet of perimeter = 0.072 man-hours
- 3 feet of perimeter = 0.108 man-hours.

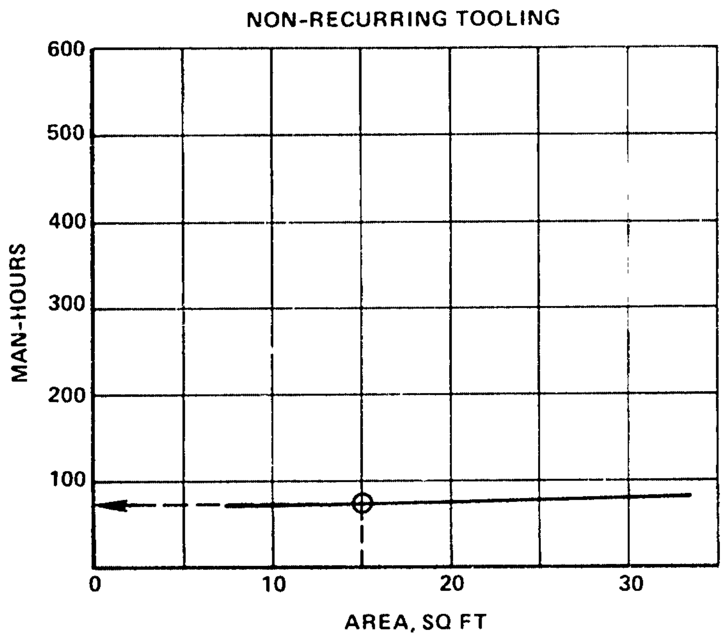
Adding DICE man-hours to base part cost now provides the manufacturing cost for the discrete part (not including direct material cost): 2.18 + 1.17 (0.072 + 0.108) = 2.39 man-hours per part.

STEEL CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS

FARNHAM ROLL







CED—S-8

SHEET-METAL AEROSPACE DISCRETE PARTS

DICE MAN-HOURS

DICE	ALUMINUM 2024	STEEL PH15-7Mo	TITANIUM 6Al-4V
A HEAT TREATMENT[1]	T62: 0.8 X BASE PART COST T81: 0.1 X BASE PART COST	NOT APPLICABLE	NOT APPLICABLE
B STANDARD JOGGLE	0.008 + (0.006 X N*)	0.008 + (0.006 X N) COLD 0.011 + (0.018 X N) HOT	0.011 + (0.018 X N)
C STANDARD FLANGED HOLE	0.010 + (0.010 X N*)	0.010 + (0.010 X N)	0.010 + (0.010 X N)
D SPECIAL LINEAL TRIM	PER FOOT: 0.021 MAN-HOURS**	PER FOOT: 0.049 MAN-HOURS**	PER FOOT: 0.061 MAN-HOURS**
E STANDARD CUTOUT	0.024 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER

*N = NUMBER OF JOGGLES OR FLANGED HOLES.

**COST INCLUDES AMORTIZED TOOLING, AMORTIZED OVER 200 UNITS

1 THIS IS A COMPOSITE FACTOR FOR ALL SHAPES AND SIZES. FOR MORE DETAILS SEE DICE 6 OR DICE 7.

DICE-1

3. EXAMPLE. TITANIUM ZEE STIFFENER OR STRINGER

Problem: Determine manufacturing cost (man-hours) of a straight 6Al-4V titanium "Z" section stringer, having the dimensions as shown on the sketch on the following page.

(1) Utilize the Format Selection Aid for Sheet Metal.

(2) Determine the appropriate format for the base part; in this case, CED-T-5.

(3) Study format determining parameters and conditions required for use. In this case, part length, in feet, and bend radius, are needed. For the purposes of this example, consider that either of the bend radius ranges indicated on the format could be used, and determine which design would be the lowest cost to manufacture. Thus, we have the following two cases for the part:

(a) Part length = 84 in. = 7 ft.
Bend radius (R) = $\geq$ 5t.

(b) Part length = 84 in. = 7 ft.
Bend radius (R) = 2t $\leq$ R $\leq$ 5t.

(4) Determine base part recurring and non-recurring tooling costs (NRTC) (man-hours) for each case using CED-T-5 and the learning curve factor of 1.17 from Example 1, page 68:

(a) Using curve (1)

- Recurring cost at unit 200 = 0.55 man-hour per part
- NRTC = 60 man-hours per 200 parts
  = 0.3 man-hour per part.

Base part cost = 0.55 (1.17) + 0.3 = 0.94 man-hour per part.

(b) Using curve (2)

- Recurring cost at unit 200 = 2.05 man-hours per part
- NRTC = 285 man-hours per 200 parts
  = 1.425 man-hours per part.

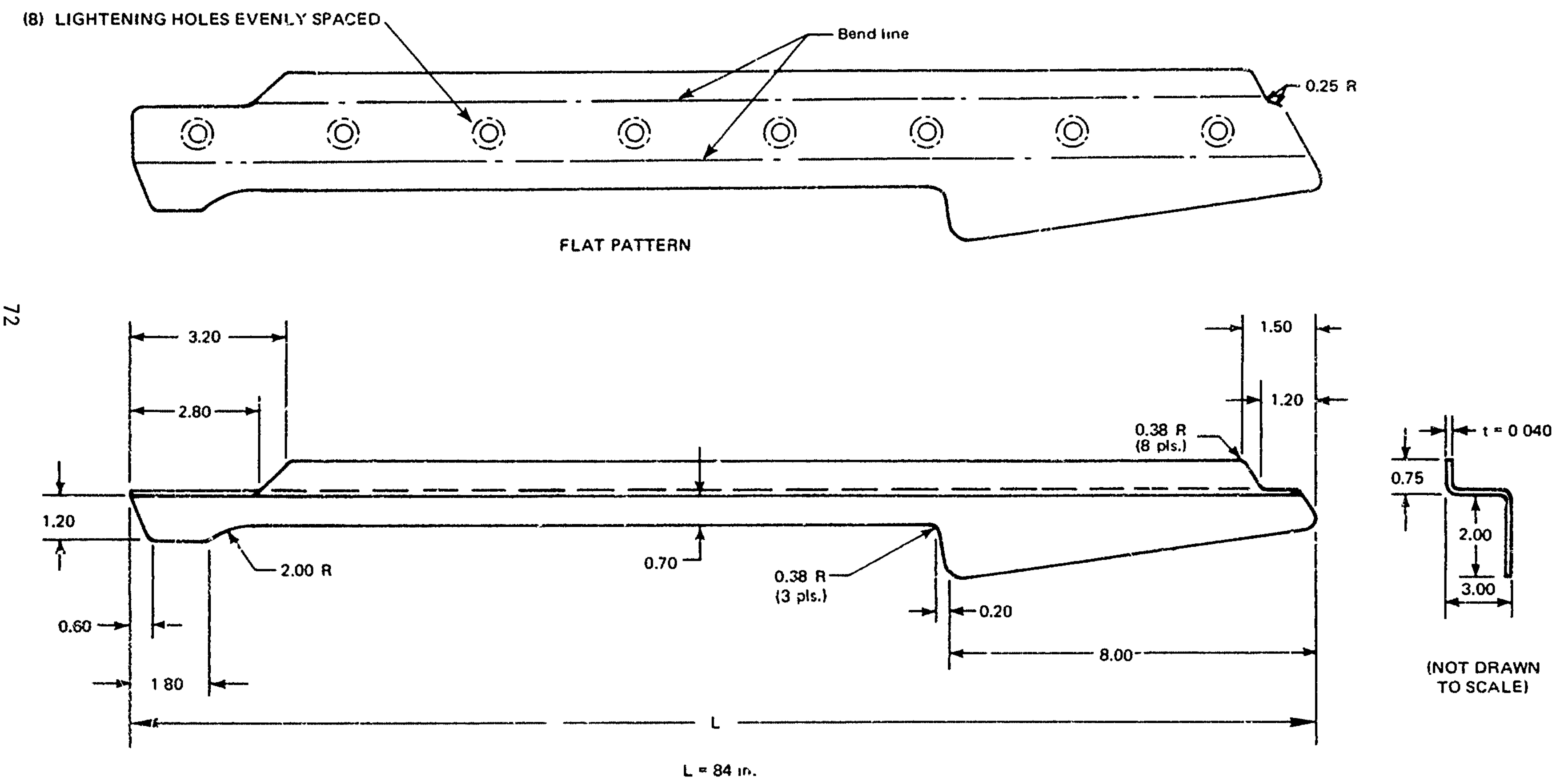
Base part cost = 2.05 (1.17) + 1.425 = 3.82 man-hours per part.

(5) Check for applicable DICE.

Example has flanged lightening holes (DICE-C) and trim prior to forming (DICE-F).

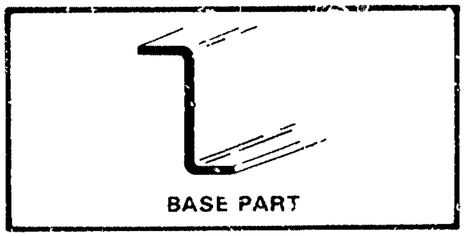
For Case (a), format CED-T-5 indicates both DICE-C and DICE-F are applicable to the brake forming method.

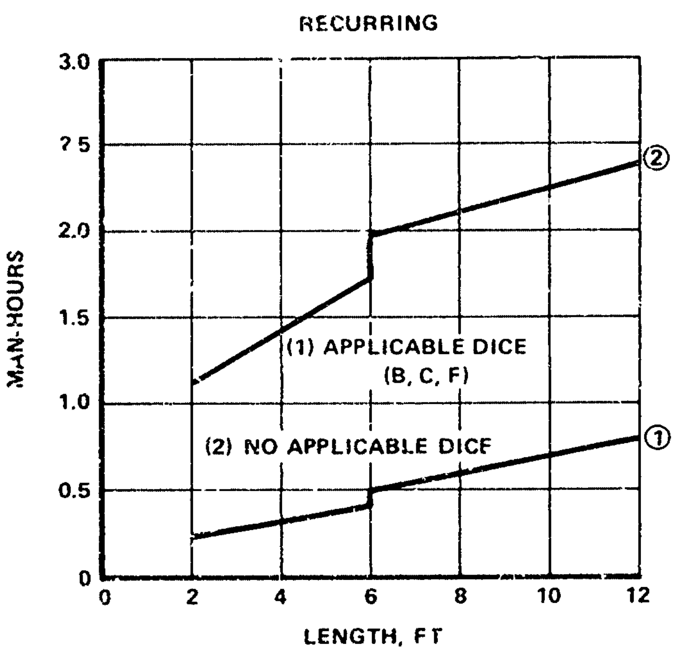
TITANIUM "Z" SECTION
CONSTANT THICKNESS
STRAIGHT

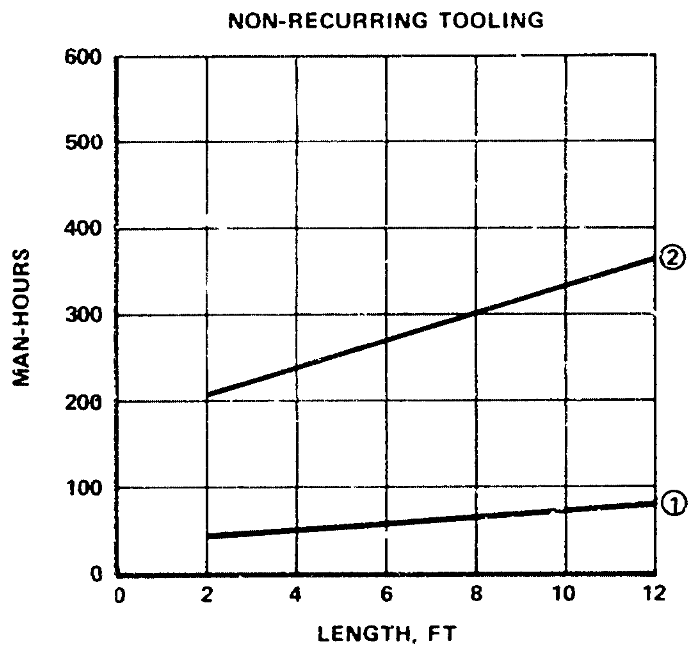


TITANIUM ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM AND PREFORM/HOT SIZE







(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t
(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

CED—T-5

For Case (b), the format indicates that no DICE are applicable for the preform/hot size method as this method permits inclusion of the DICE at negligible additional cost. However, in the case of the brake forming operation, the DICE require additional operations. Thus, Case (b) has no additional cost for the flanged holes and the trim.

DICE costs for Case (a) are found by again utilizing the Format Selection Aid and determining that formats DICE-3 and DICE-11 are applicable. The parameters required are the number of flanged holes (DICE-3) and perimeter trim (DICE-11). Eight flanged holes are required in the airframe part and the perimeter trim required is approximately 180 inches. The DICE costs are:

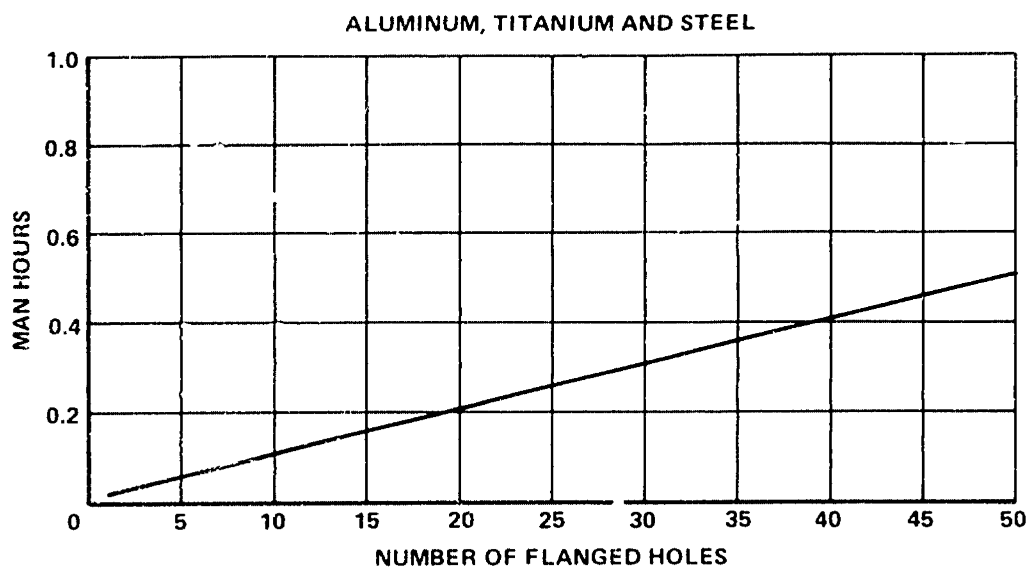
- Flanged holes: 0.09 man-hour per part
- Trim prior to forming: 0.455 man-hour per part.

Total manufacturing costs (man-hours), excluding direct material cost, are for:

- Case (a): 1.17 (0.55 + 0.09 + 0.455) + 0.3 = 1.58 man-hours
- Case (b): 3.82 man-hours.

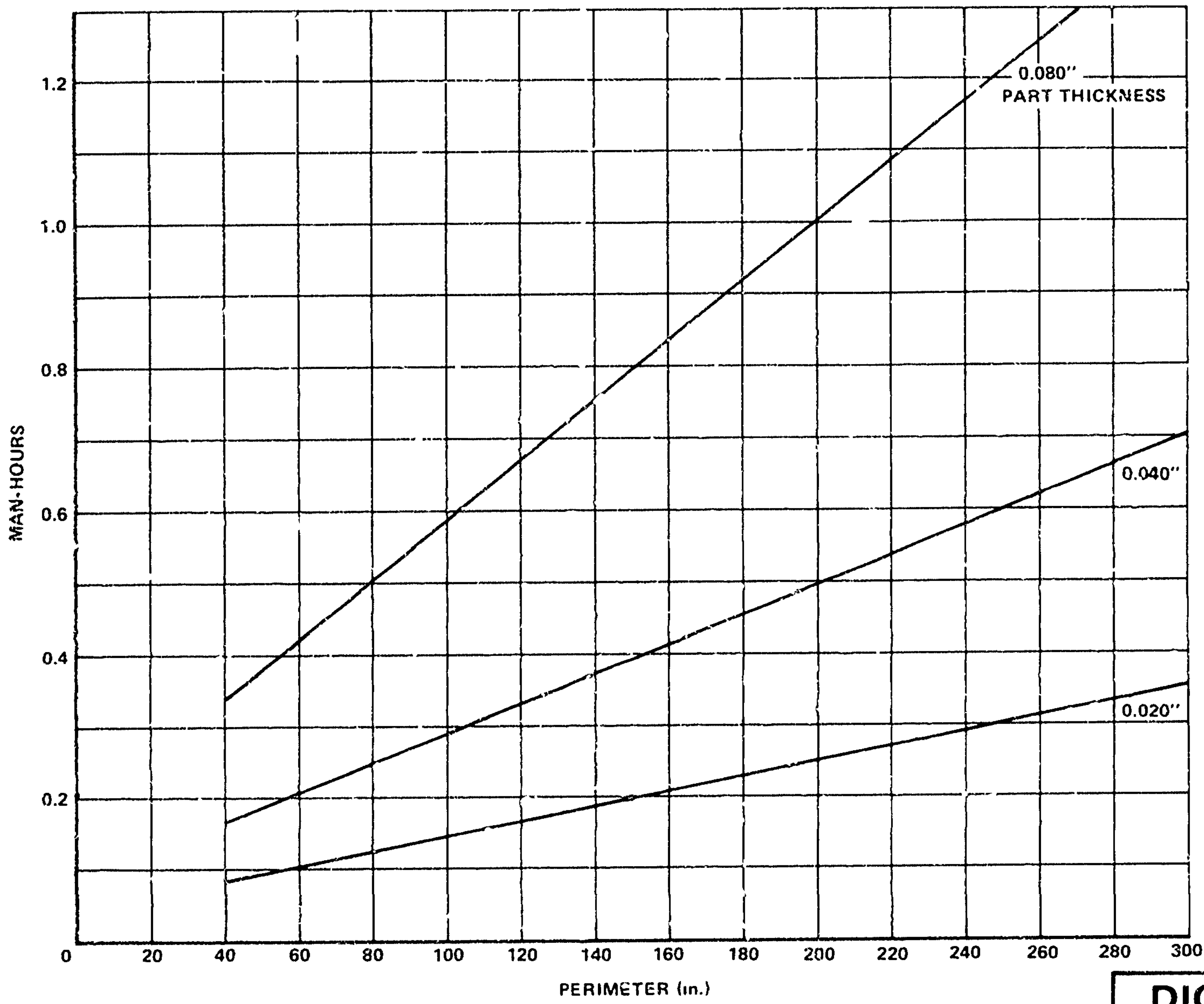
This shows that it is less costly to produce the part with a bend radius of $\geq$ 5t, if the design constraints permit.

SHEET-METAL AEROSPACE DISCRETE PARTS— FLANGED HOLE RECURRING COST



DICE-3

TITANIUM STACK MILL PRIOR TO FORMING



DICE-11

FORMATS FOR

ALUMINUM SHEET-METAL AEROSPACE DISCRETE PARTS

LOWEST COST PROCESSES

FORMATS FOR ALUMINUM SHEET-METAL AEROSPACE DISCRETE PARTS LOWEST COST PROCESSES

(1) See ground rules for considerations and limitations.

(2) Step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq 5T$
- At elevated temperature forming $\geq 2T$.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to making a selection of a material or design concept based on the cost of manufacturing.

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as heat treatment, cut-outs, and joggles.

(2) Designer-Influenced Cost Elements (DICE): Includes joggles, cut-outs, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 4 . FORMATS FOR ALUMINUM SHEET-METAL AEROSPACE DISCRETE PARTS

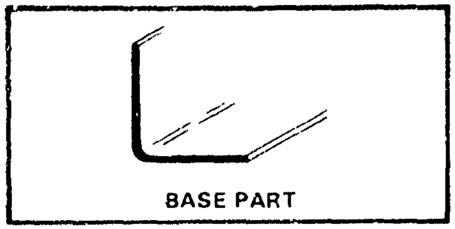
Format Number	Format Title
CED-A-1	Aluminum Angle, Straight Member, Lowest Cost Process: Brake Form
CED-A-2	Aluminum Angle, Cylindrically Contoured Member, Lowest Cost Process: Brake/Roll
CED-A-3	Aluminum Angle, Non-Cylindrically Contoured Member, Lowest Cost Process: Rubber Press
CED-A-4	Aluminum Channel, Straight Member, Lowest Cost Process: Brake Form
CED-A-5	Aluminum Channel, Cylindrically Contoured Member, Lowest Cost Process: Brake/Roll
CED-A-6	Aluminum Channel, Non-Cylindrically Contoured Member, Lowest Cost Process: Rubber Press
CED-A-7	Aluminum Zee, Straight Member, Lowest Cost Process: Brake Form
CED-A-8	Aluminum Zee, Cylindrically Contoured Member, Lowest Cost Process: Brake/Roll
CED-A-9	Aluminum Zee, Non-Cylindrically Contoured Member, Lowest Cost Process: Rubber Press
CED-A-10	Aluminum Lipped Zee, Straight Member, Lowest Cost Process: Brake Form
CED-A-11	Aluminum Lipped Zee, Cylindrically Contoured Member, Lowest Cost Process: Brake/Roll
CED-A-12	Aluminum Lipped Zee, Non-Cylindrically Contoured Member, Lowest Cost Process: Brake/Stretch
CED-A-13	Aluminum J, Straight Member, Lowest Cost Process: Brake Form
CED-A-14	Aluminum J, Cylindrically Contoured Member, Lowest Cost Process: Brake/Roll
CED-A-15	Aluminum J, Non-Cylindrically Contoured Member, Lowest Cost Process: Brake/Stretch

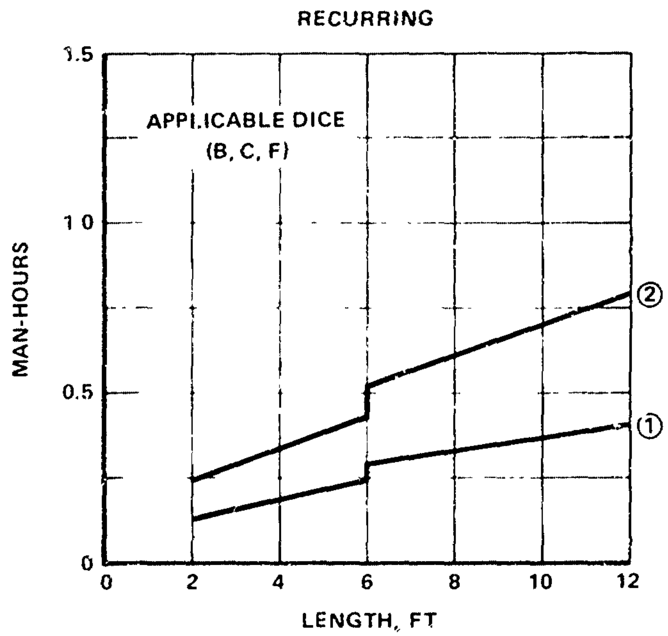
TABLE 4 . (Continued)

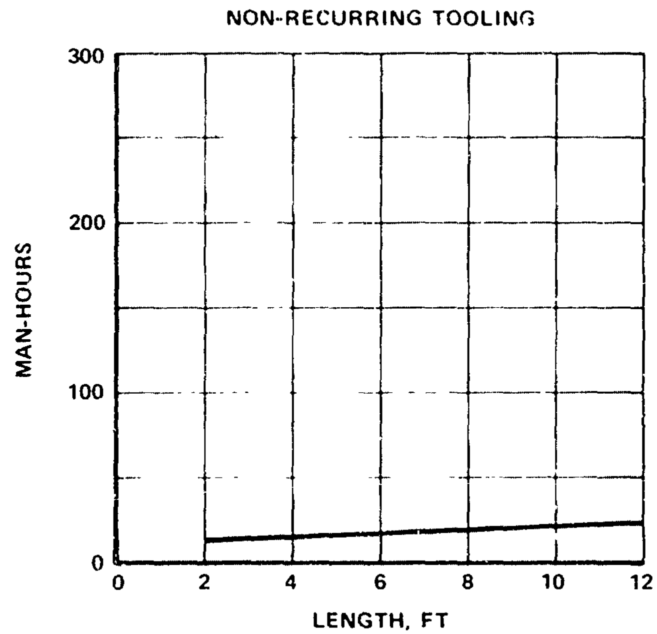
Format Number	Format Title
CED-A-16	Aluminum Lipped Hat, Straight Member, Lowest Cost Process: Brake Form
CED-A-17	Aluminum Lipped Hat, Cylindrically Contoured Member, Lowest Cost Process: Brake/Roll
CED-A-18	Aluminum Lipped Hat, Non-Cylindrically Contoured Member, Lowest Cost Process: Brake/Stretch
CED-A-19	Aluminum Flat Sheet, Lowest Cost Process (Routing Applicable Only)
CED-A-20	Aluminum Cylindrical Curvature Skin, Lowest Cost Process: Farnham Roll
CED-A-21	Aluminum Non-Cylindrical Curvature Skin, Lowest Cost Process: Stretch Form
CED-A-22	Aluminum Fairing, Lowest Cost Process: Drop Hammer
CED-A-23	Aluminum Rib, Lowest Cost Process: Rubber Press
CED-A-24	Aluminum Beaded Panel, Lowest Cost Process: Rubber Press

ALUMINUM ANGLE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





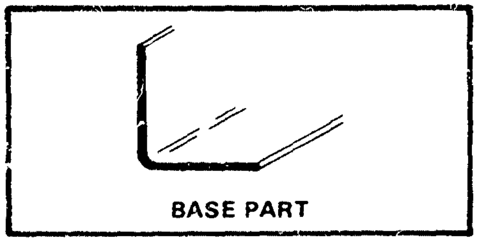


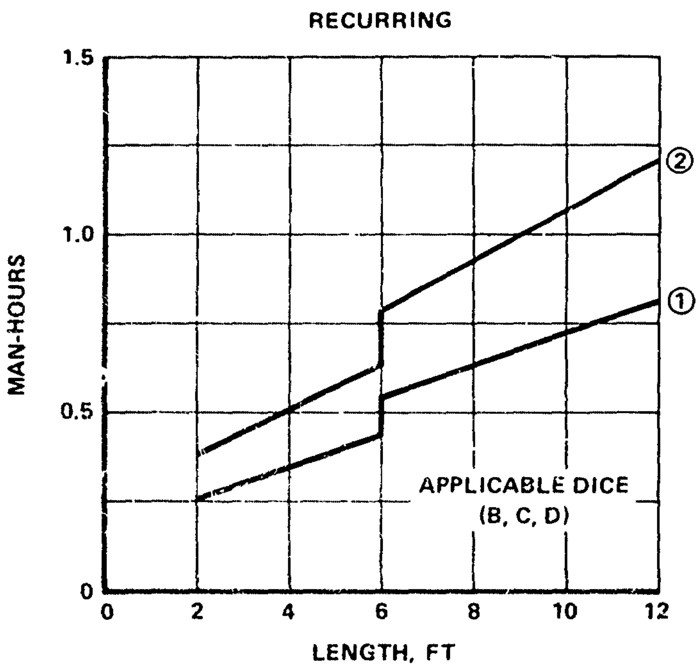
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

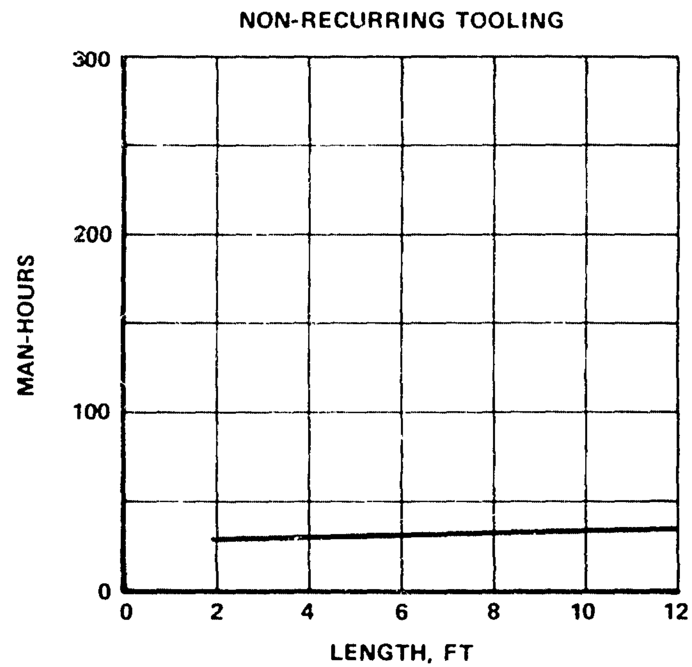
CED—A-1

ALUMINUM ANGLE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





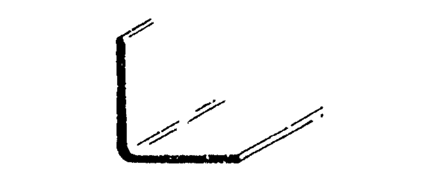


(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

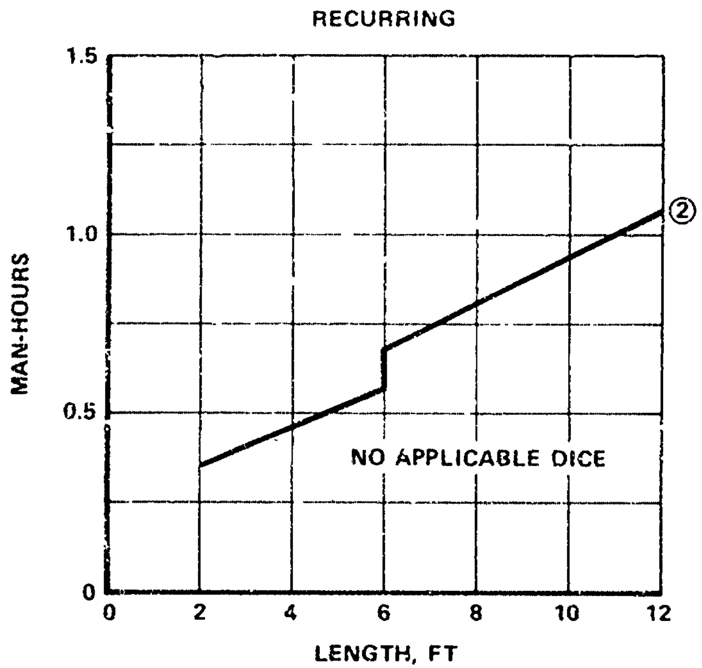
CED—A-2

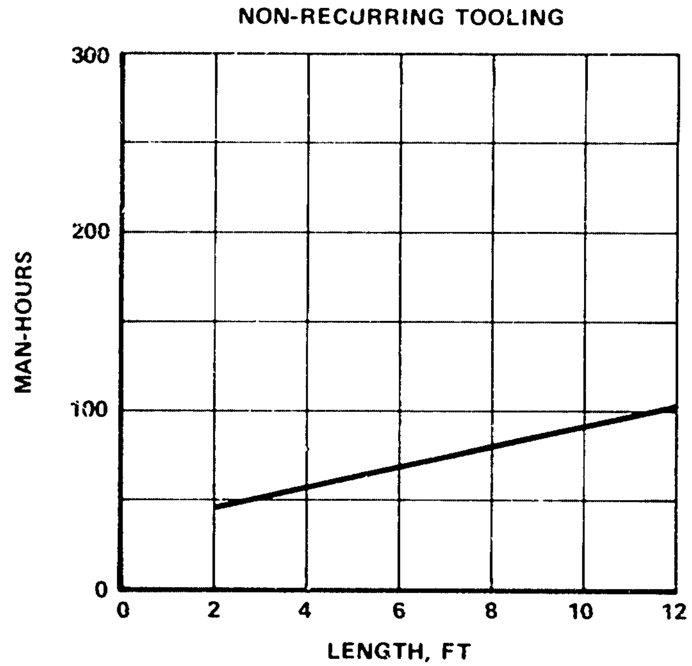
ALUMINUM ANGLE, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

RUBBER PRESS



BASE PART





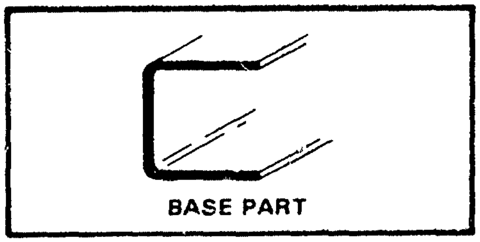
*NO REVERSE CURVES

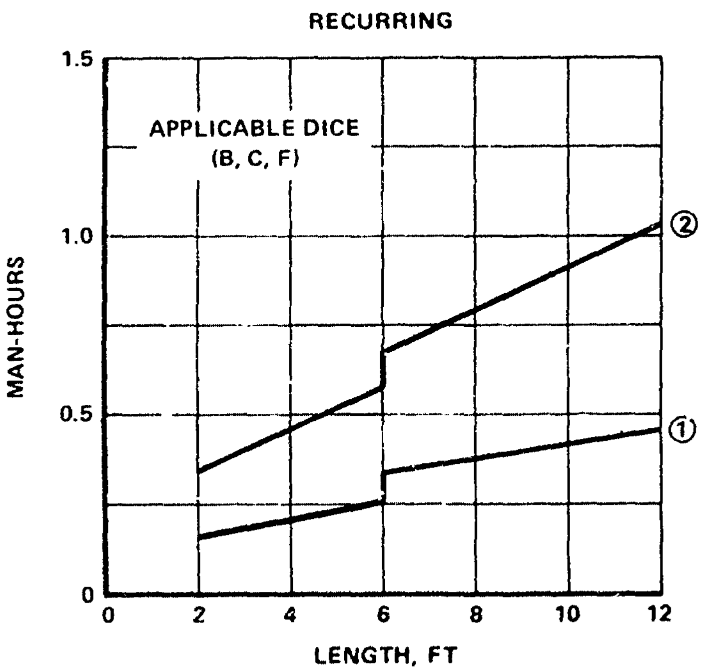
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

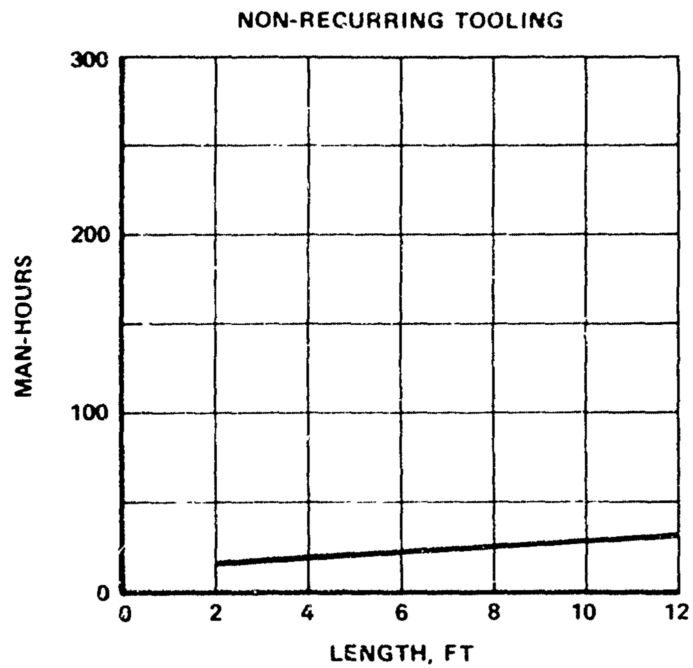
CED—A-3

ALUMINUM CHANNEL, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





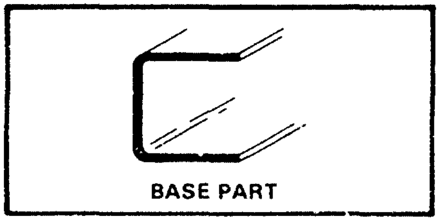


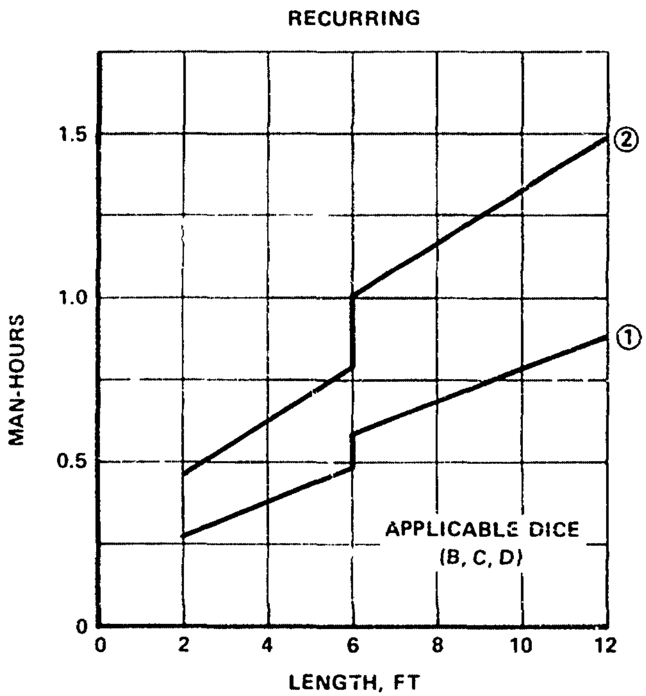
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

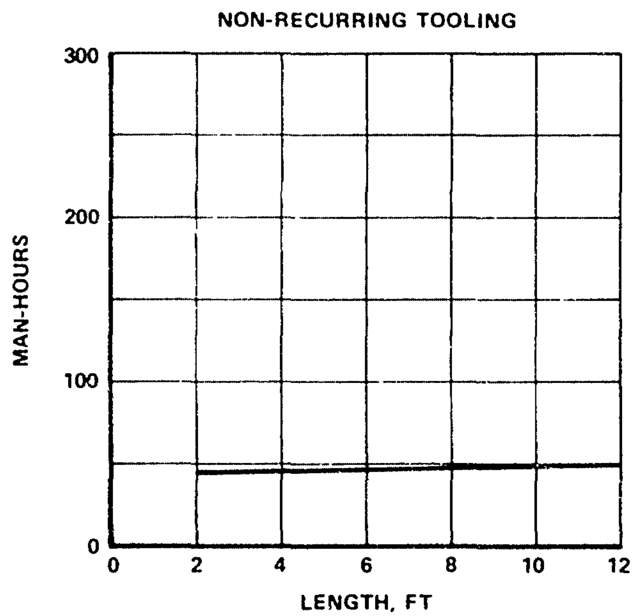
CED—A-4

ALUMINUM CHANNEL, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





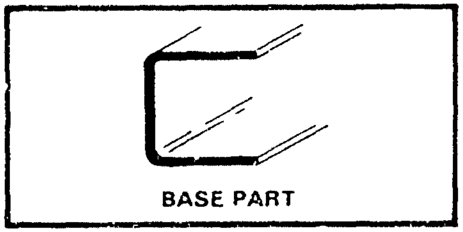


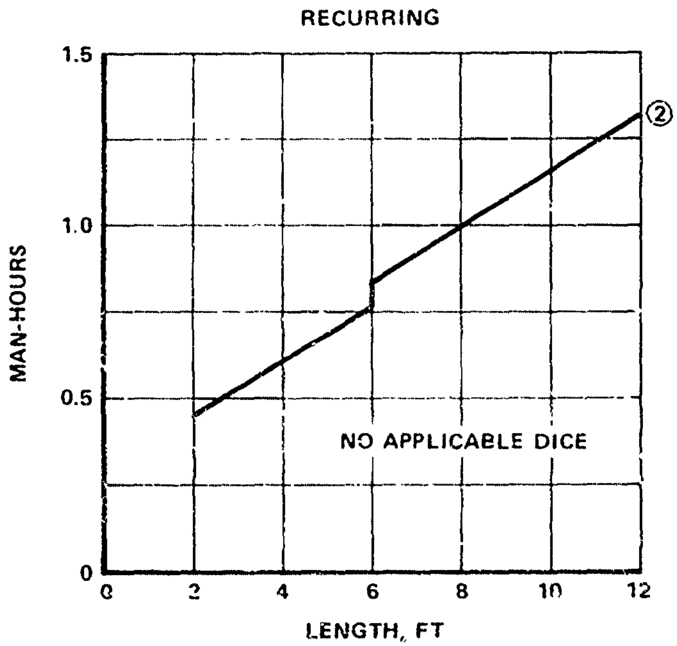
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

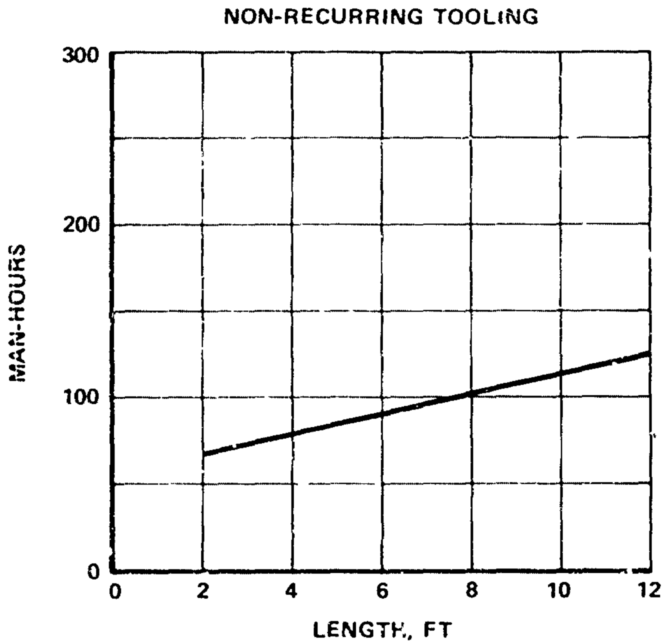
CED—A-5

ALUMINUM CHANNEL, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

RUBBER PRESS







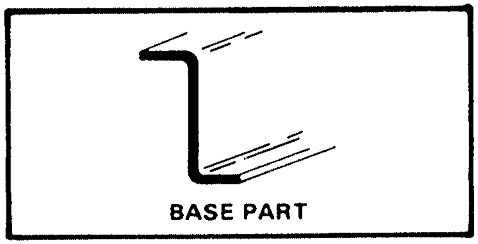
*NO REVERSE CURVES

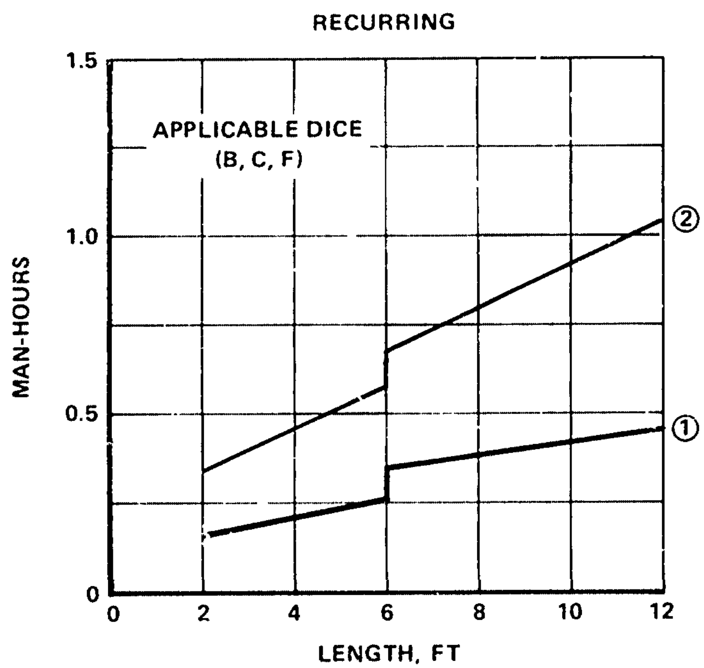
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER, MINIMUM BEND RADIUS = 1.5t

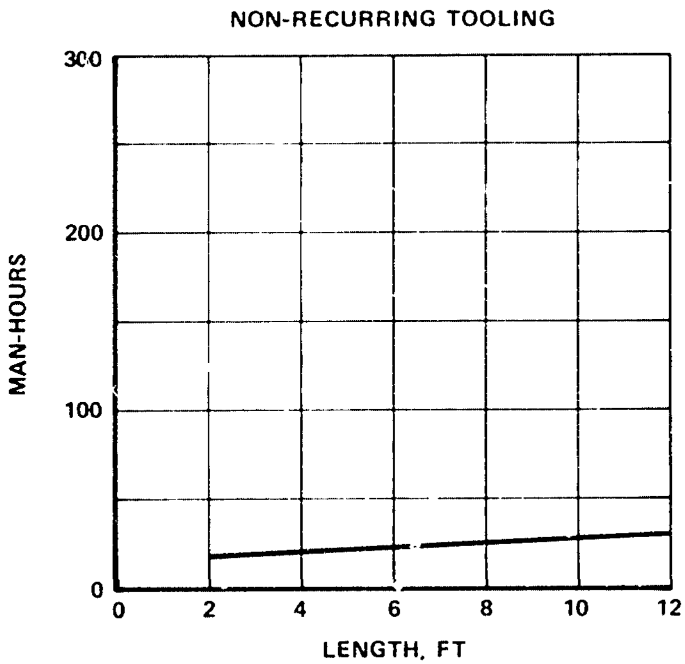
CED—A-6

ALUMINUM ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





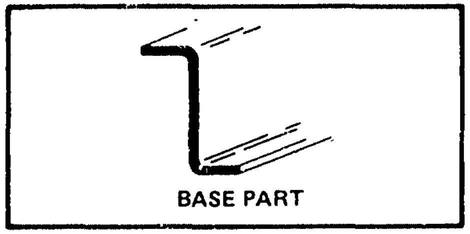


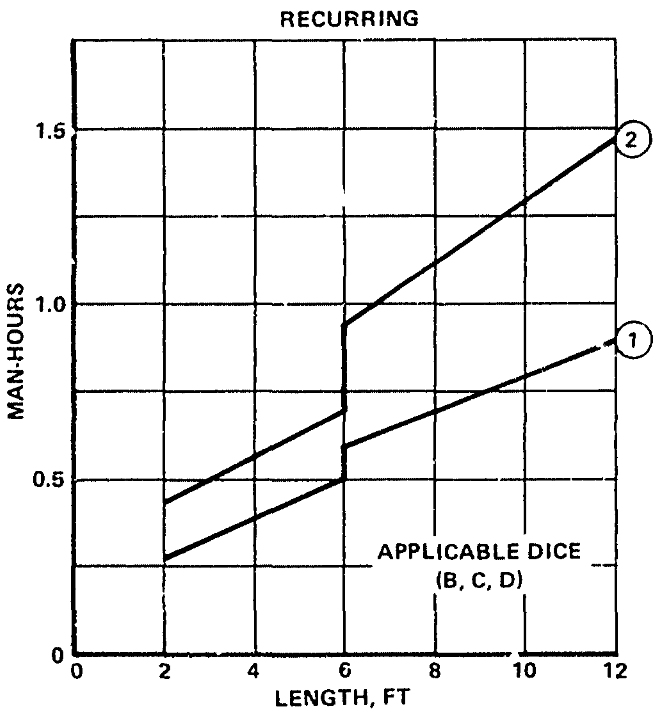
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

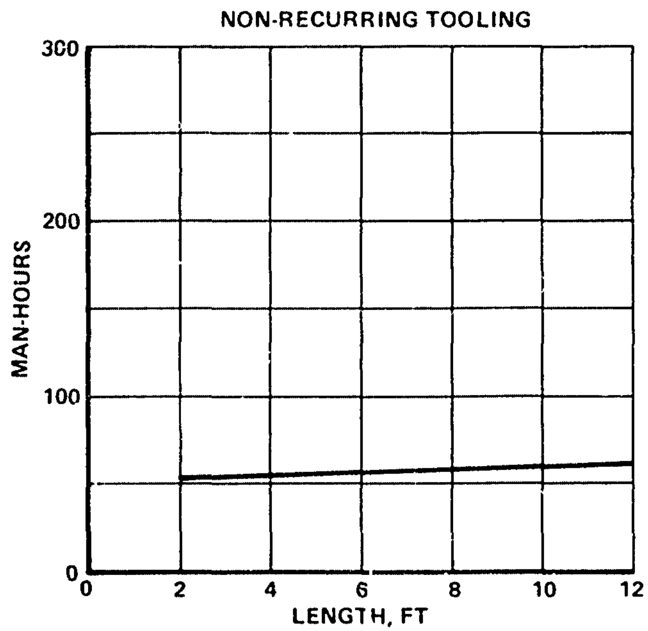
CED—A-7

ALUMINM ZEE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





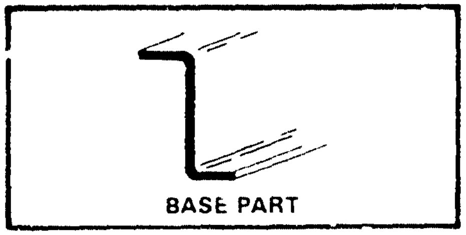


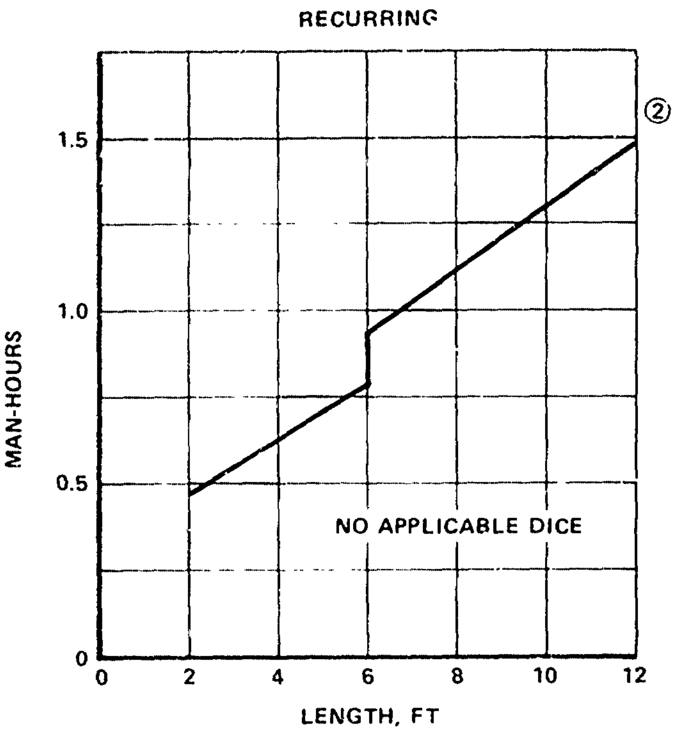
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION: T62 FINAL TEMPER: MINIMUM BEND RADIUS = 1.5t

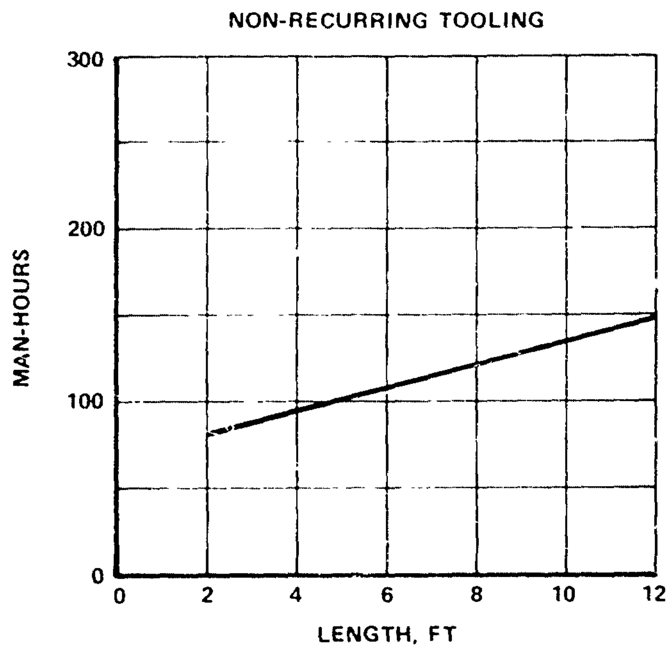
CED—A-8

ALUMINUM ZEE, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

RUBBER PRESS







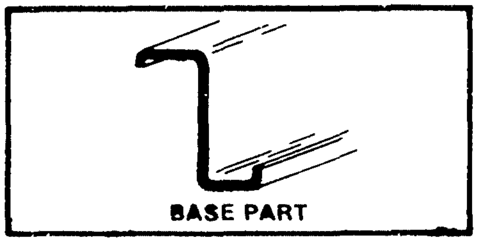
*NO REVERSE CURVES

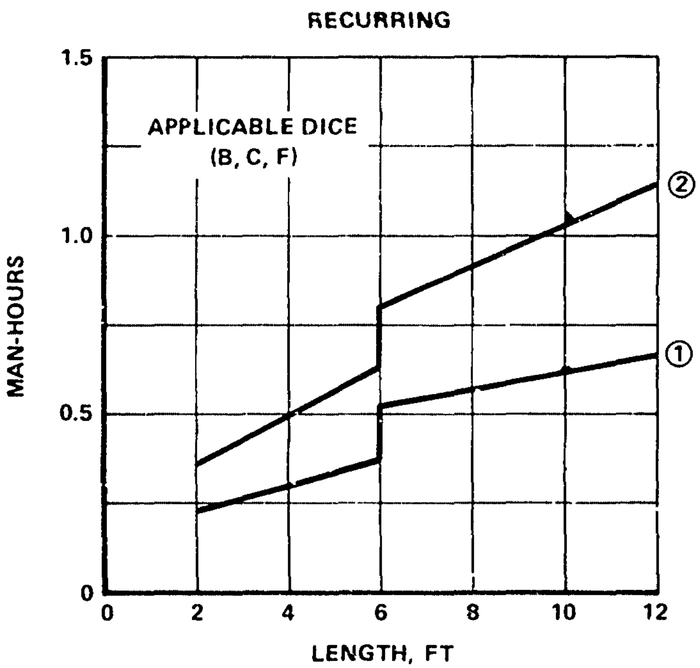
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1 5t

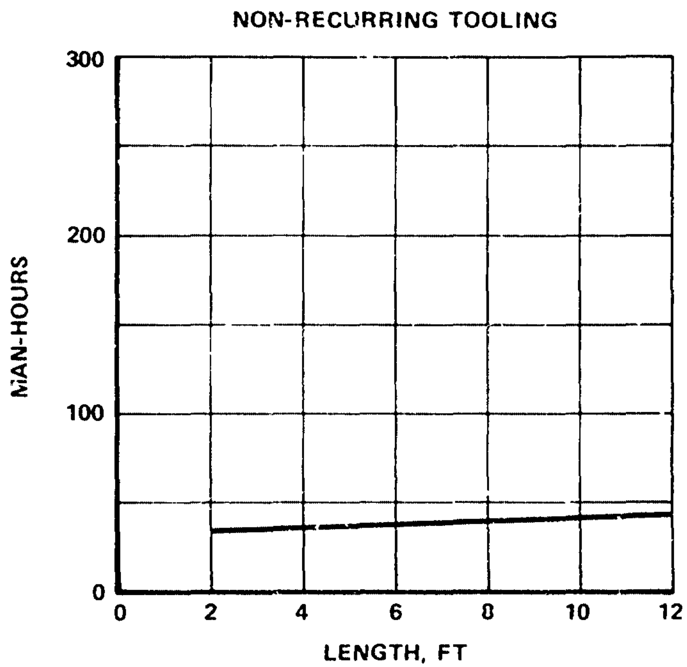
CED—A-9

ALUMINUM LIPPED ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





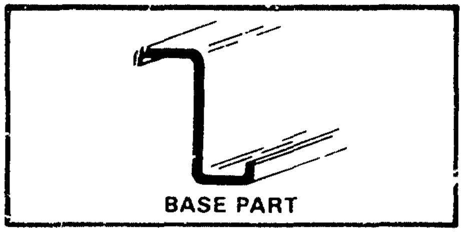


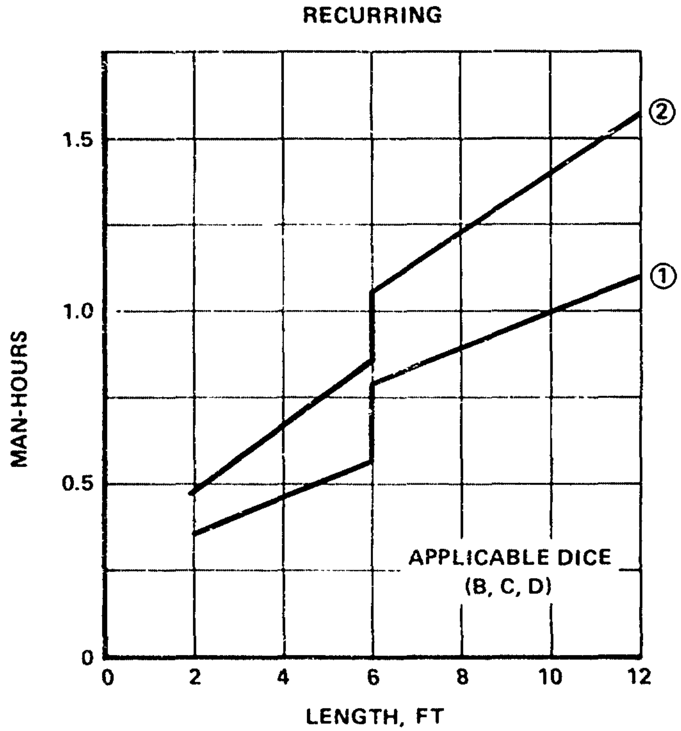
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

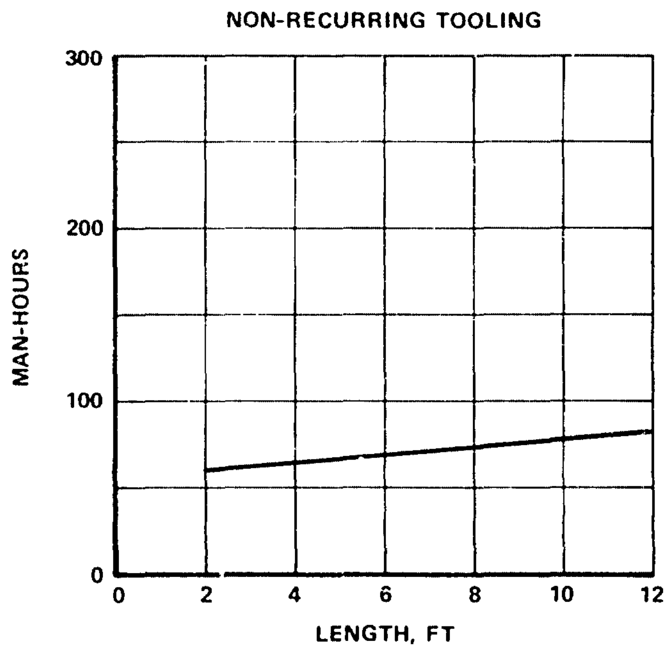
CED—A-10

ALUMINUM LIPPED ZEE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





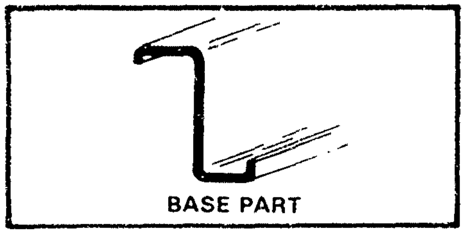


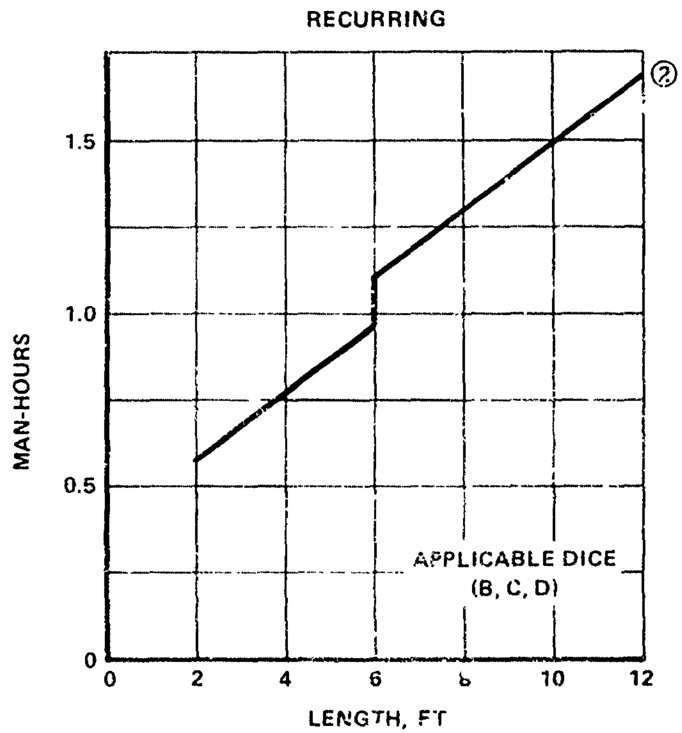
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT); MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

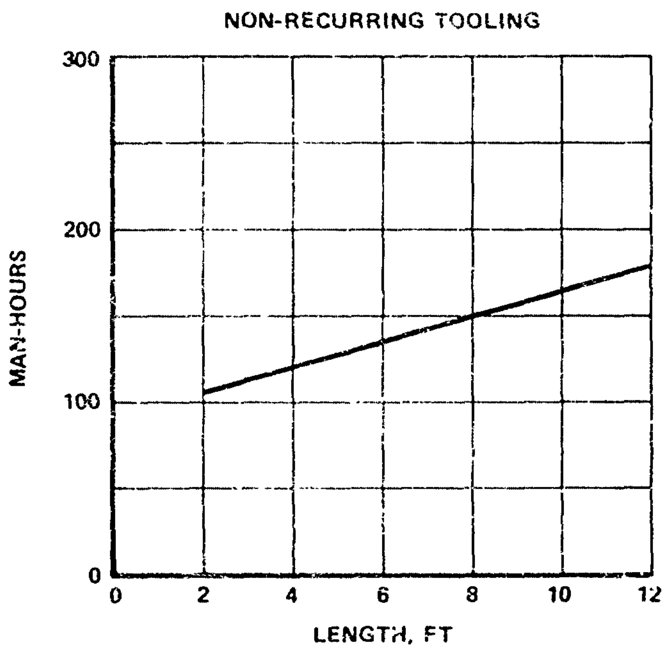
CED—A-11

ALUMINUM LIPPED ZEE, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

BRAKE/STRETCH





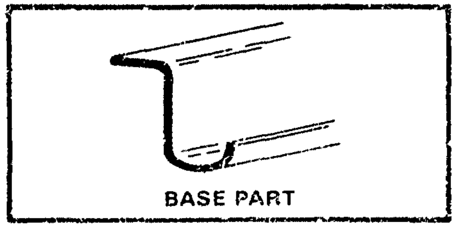


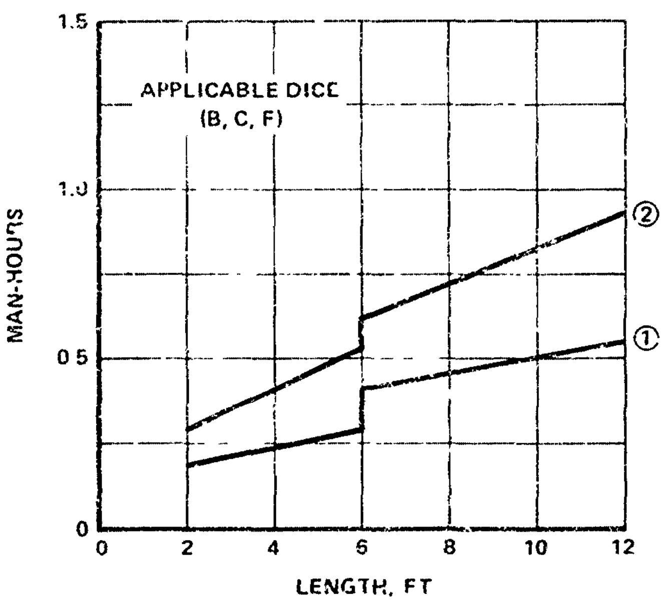
*NO REVERSE CURVES
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

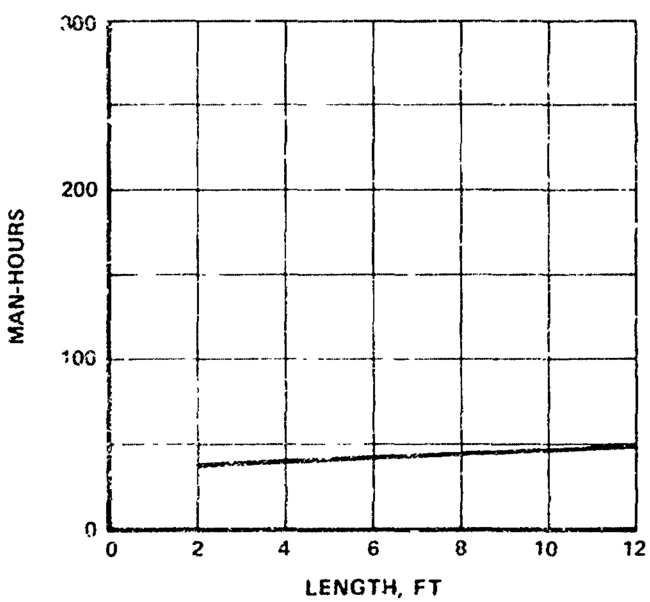
CED—A-12

ALUMINUM J, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM





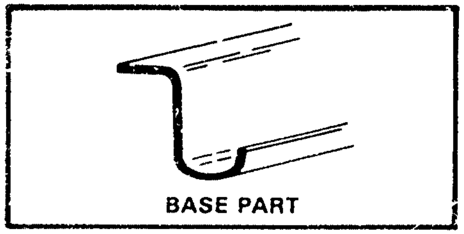


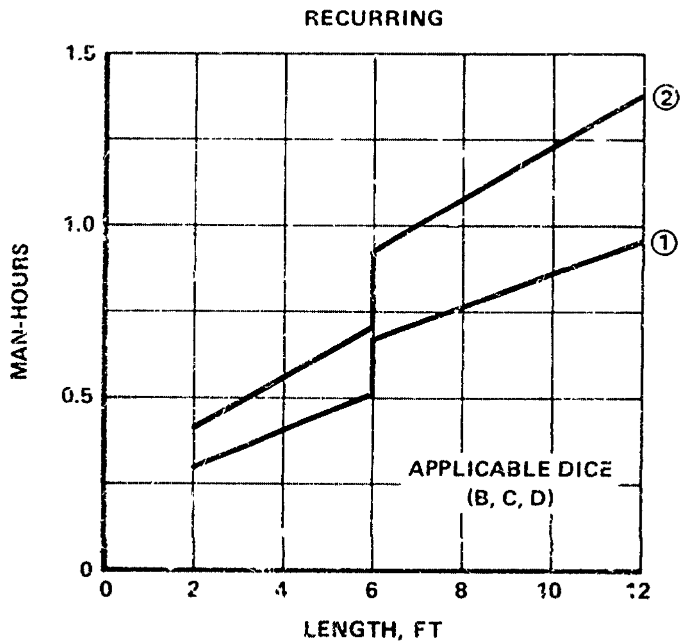
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

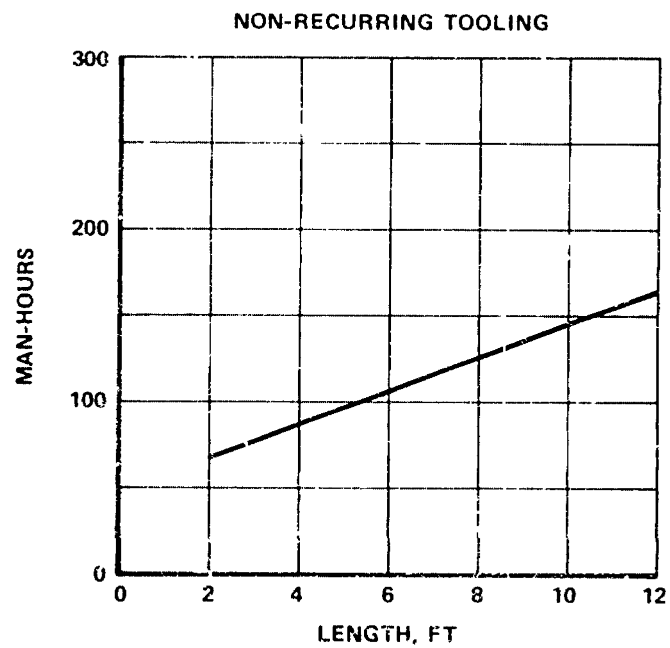
CED—A-13

ALUMINUM J. CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

BRAKE/ROLL





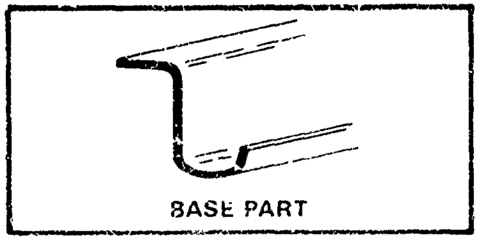


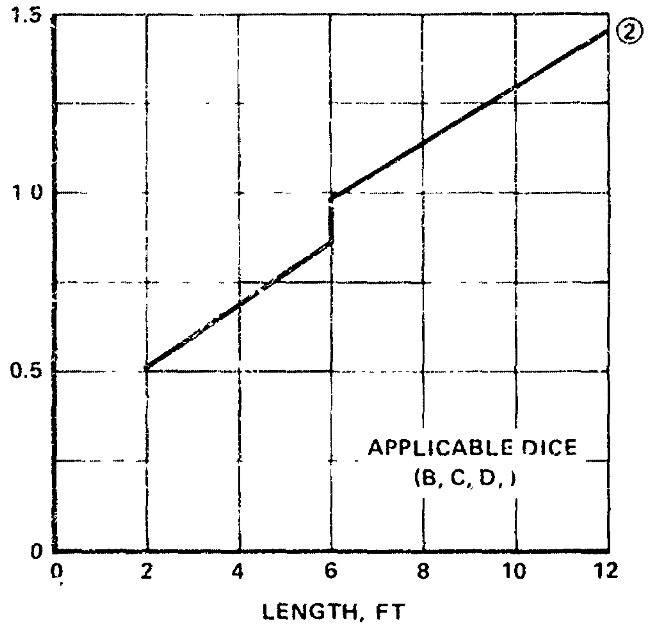
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

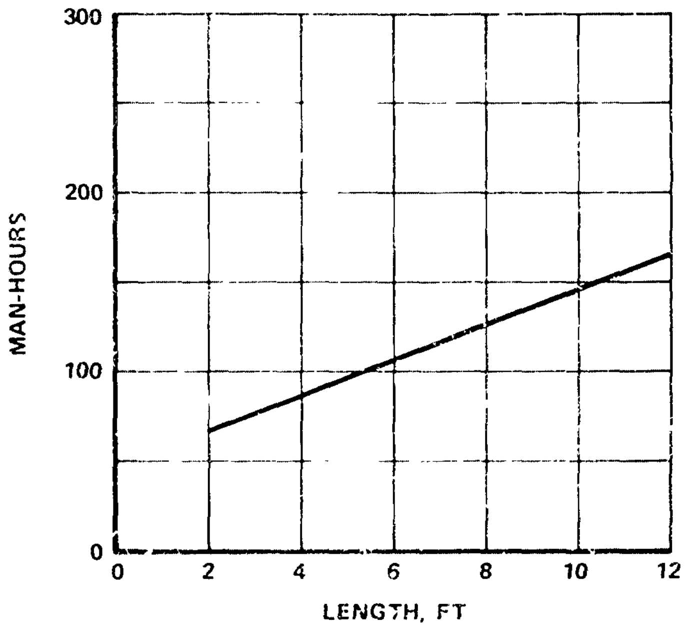
CED—A-14

ALUMINUM J, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS

BRAKE/STRETCH







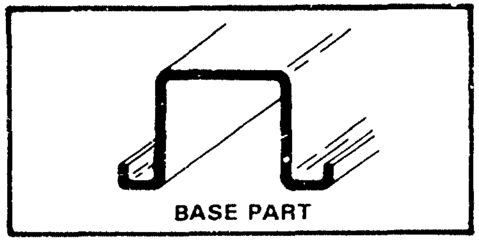
*NO REVERSE CURVES

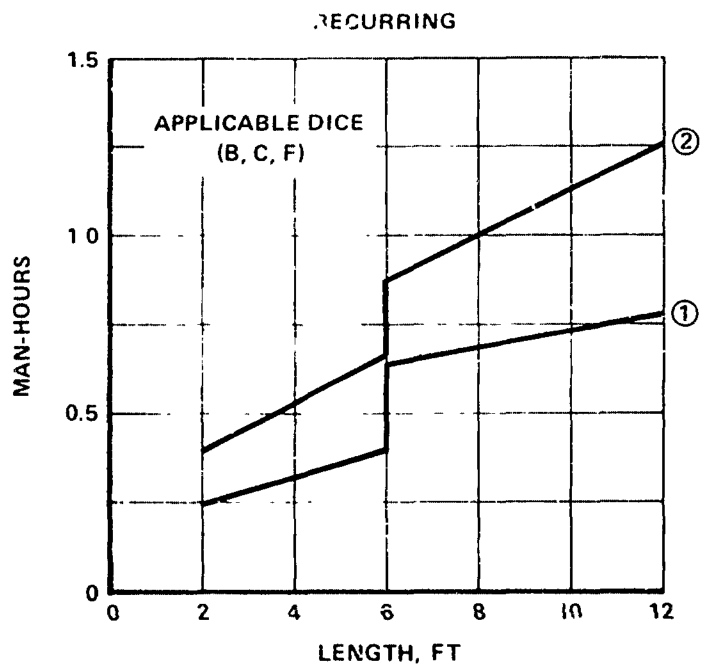
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

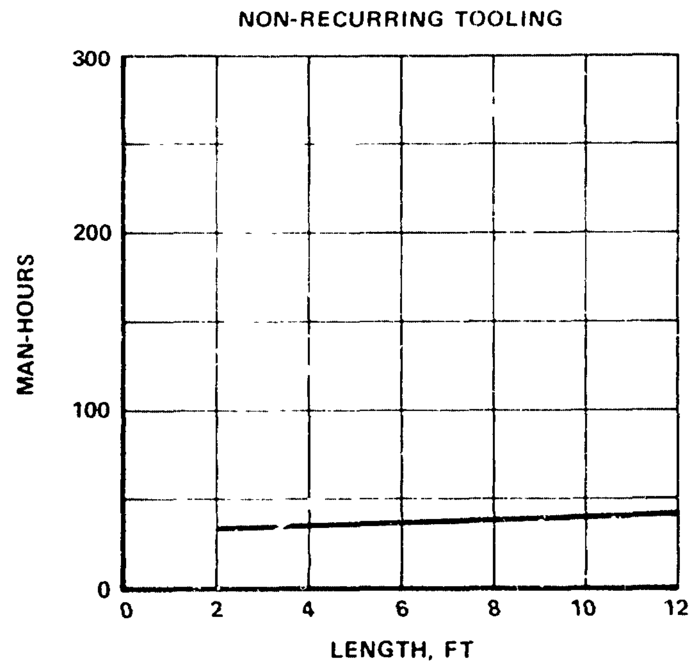
CED—A-15

ALUMINUM LIPPED HAT, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM

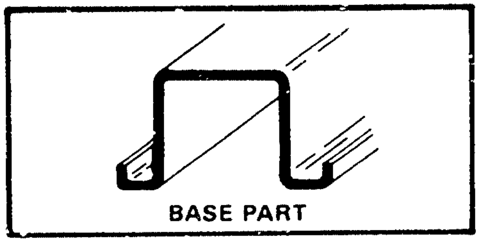




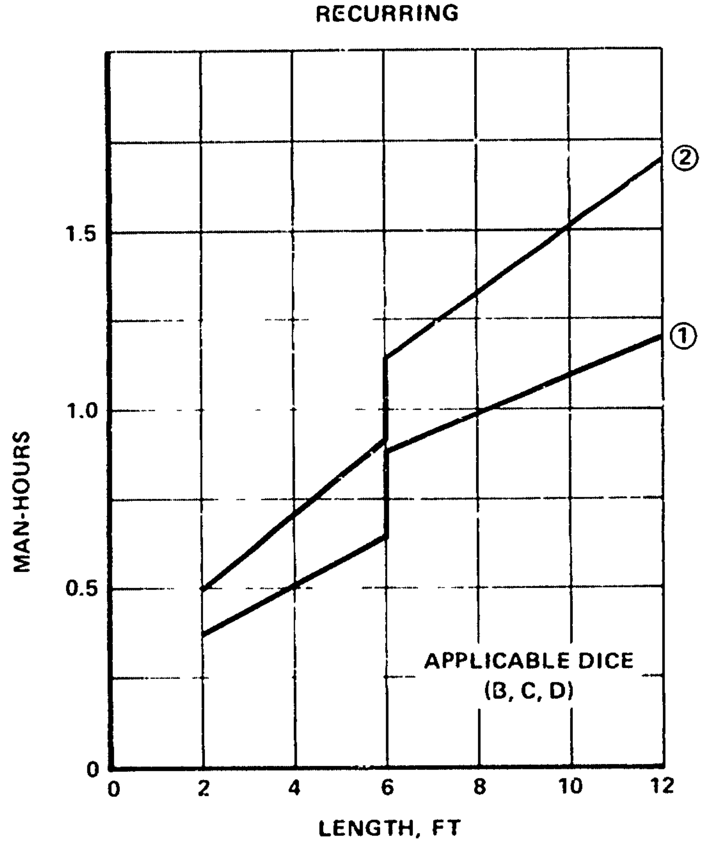


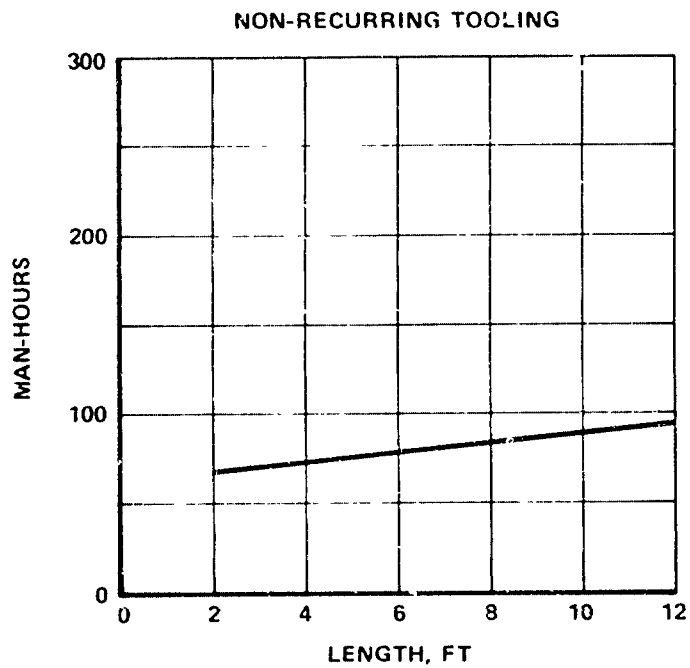
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

CED—A-16



ALUMINUM LIPPED HAT, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS BRAKE/ROLL

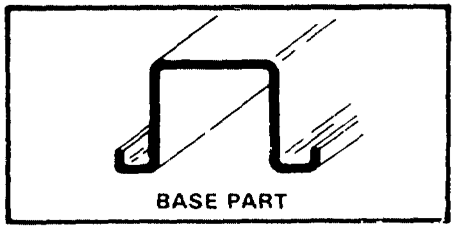




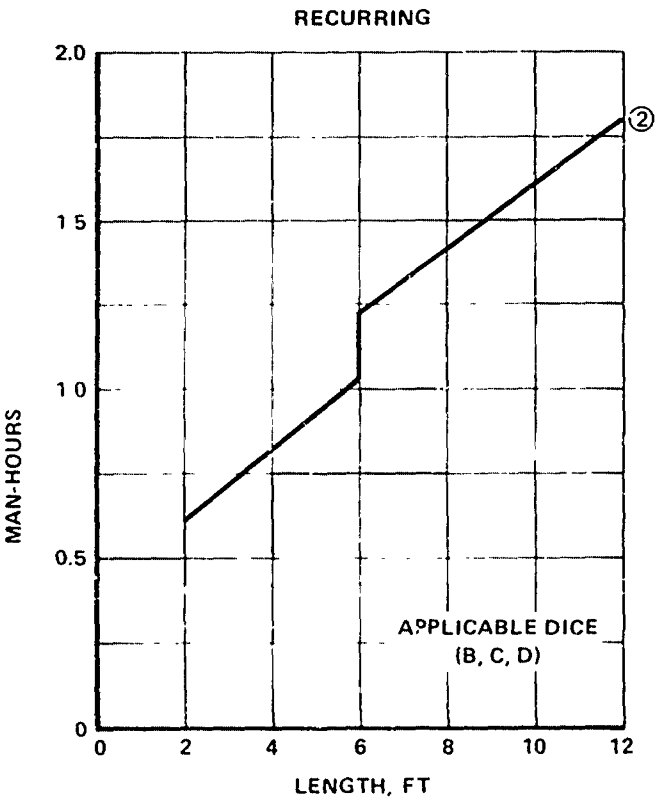
(1) PART FORMED IN T3 CONDITION (NO SOLUTION HEAT TREAT), MINIMUM BEND RADIUS = 3.5t
(2) PART FORMED IN "O" OR "W" CONDITION, T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

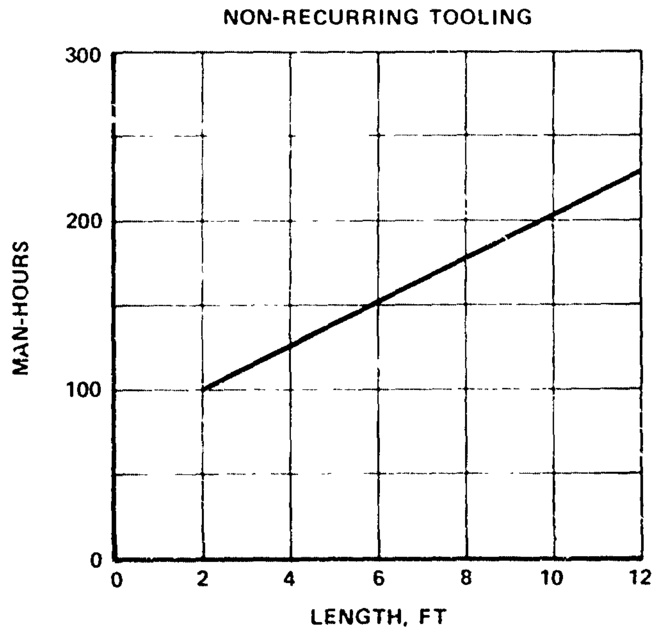
CED—A-17

ALUMINUM LIPPED HAT, NON-CYLINDRICALLY CONTOURED MEMBER,* LOWEST COST PROCESS



BRAKE/STRETCH



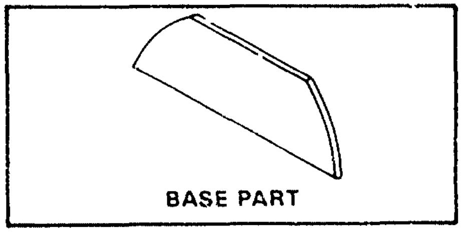


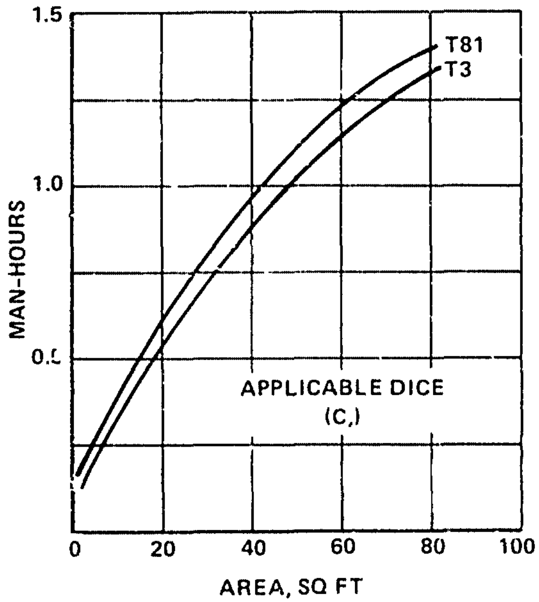
*NO REVERSE CURVES

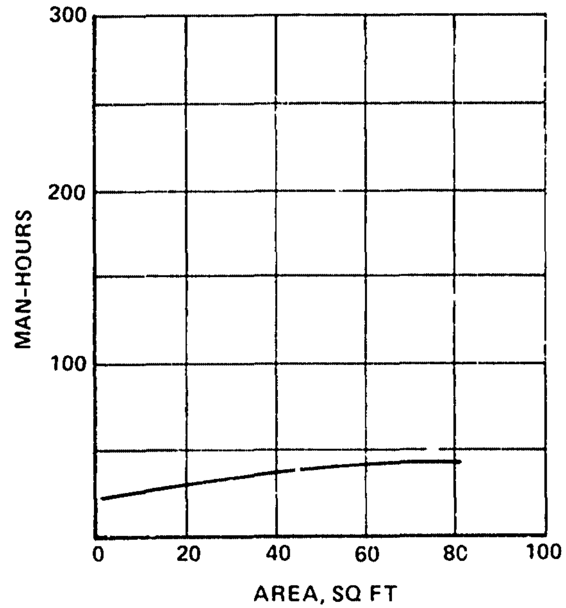
(2) PART FORMED IN "O" OR "W" CONDITION; T62 FINAL TEMPER; MINIMUM BEND RADIUS = 1.5t

CED—A-18

ALUMINUM FLAT SHEET, LOWEST COST PROCESS
(ROUTING APPLICABLE ONLY)



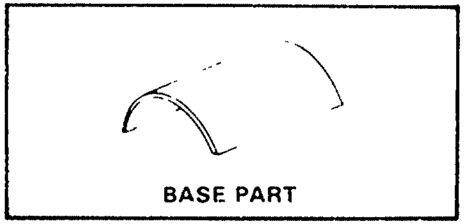


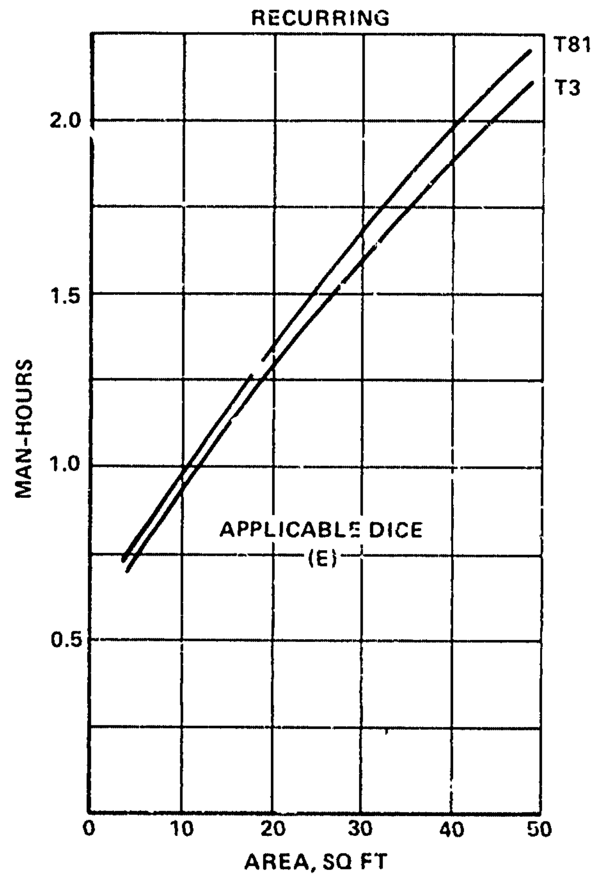


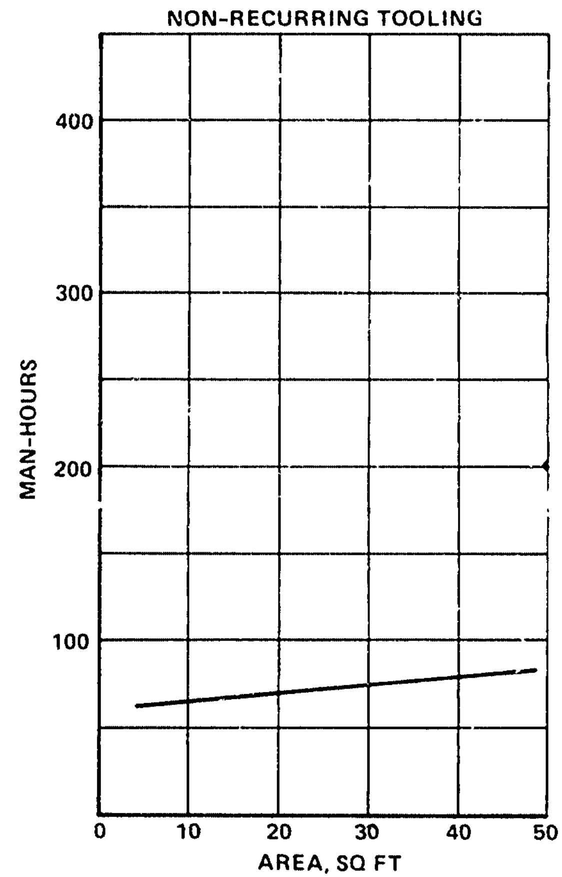
CED—A-19

ALUMINUM CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS FARNHAM ROLL

(PERIMETER TRIM INCLUDED)



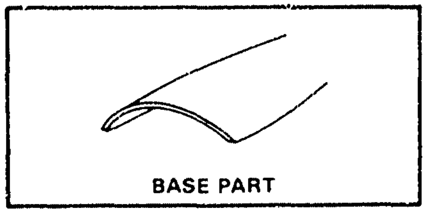


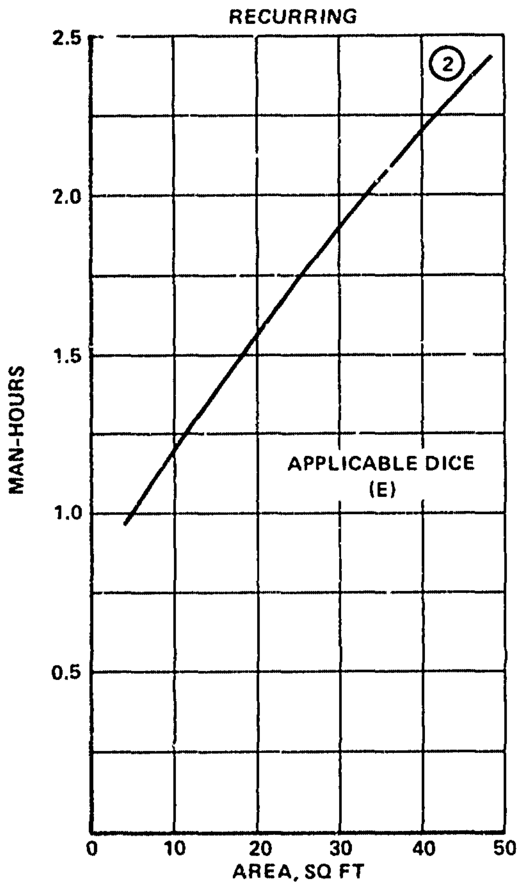


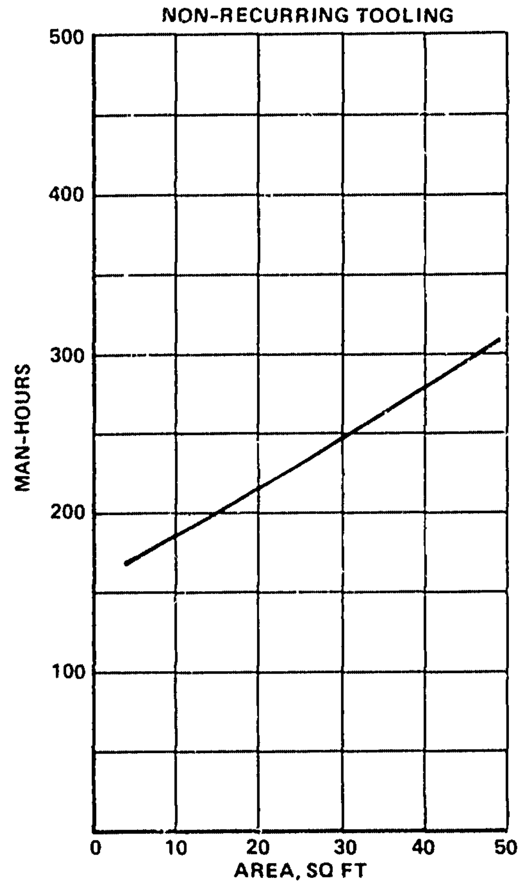
CED—A-20

ALUMINUM NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS

STRETCH FORM



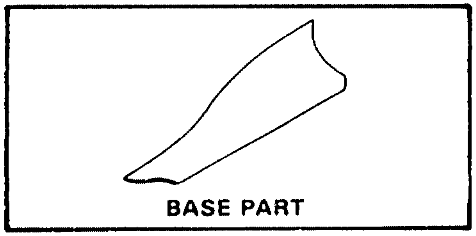




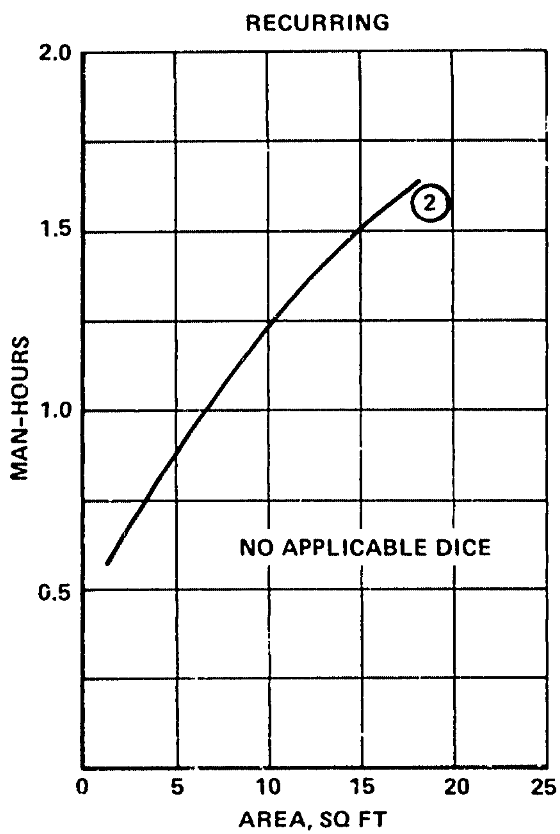
*NO REVERSE CURVES

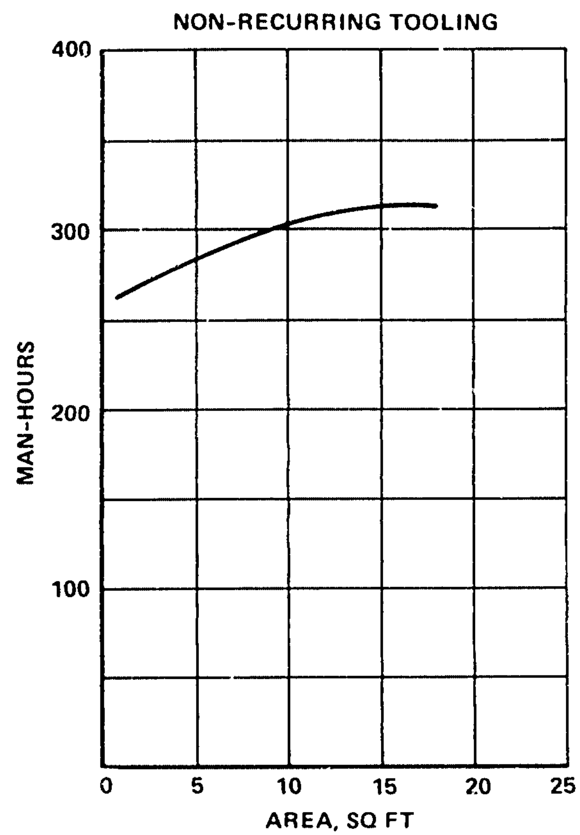
(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62

CED—A-21



ALUMINUM FAIRING, LOWEST COST PROCESS DROP HAMMER (INCLUDES PROCESS AND TRIM)

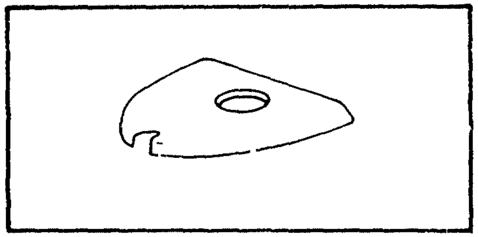


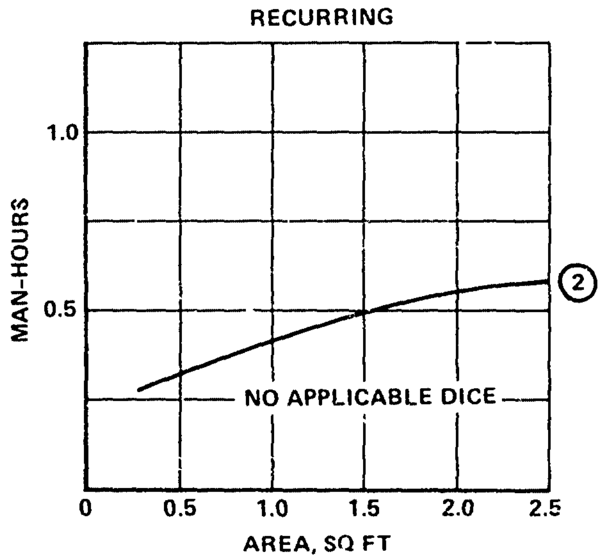


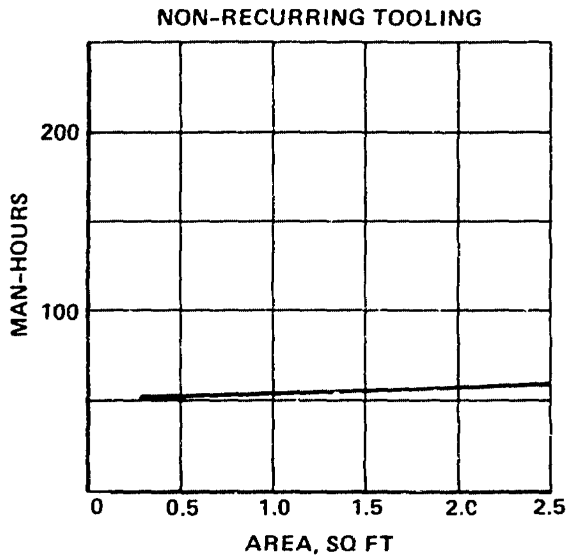
(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62

CED—A-22

ALUMINUM RIB, LOWEST COST PROCESS
RUBBER PRESS

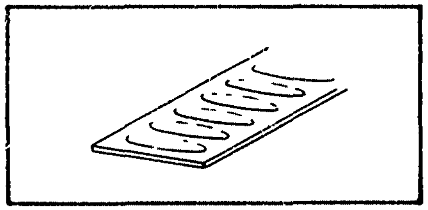






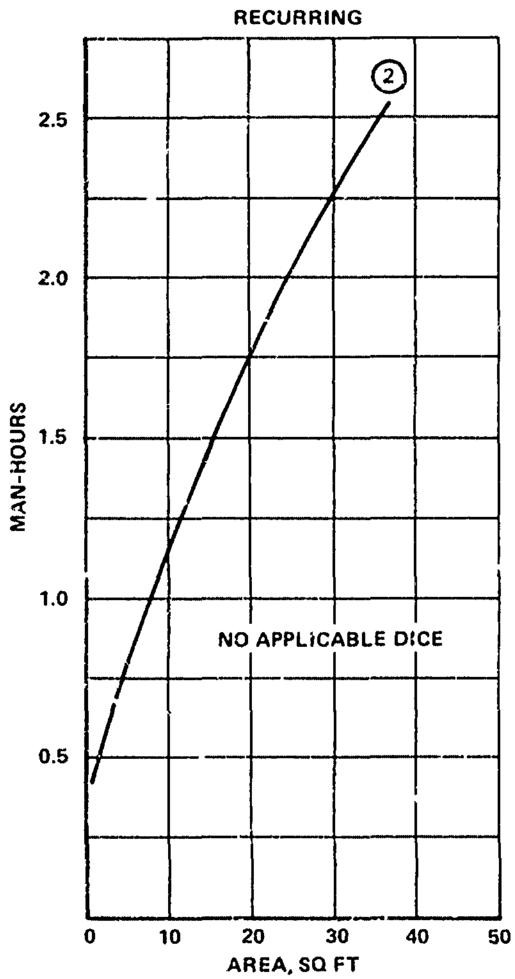
(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62

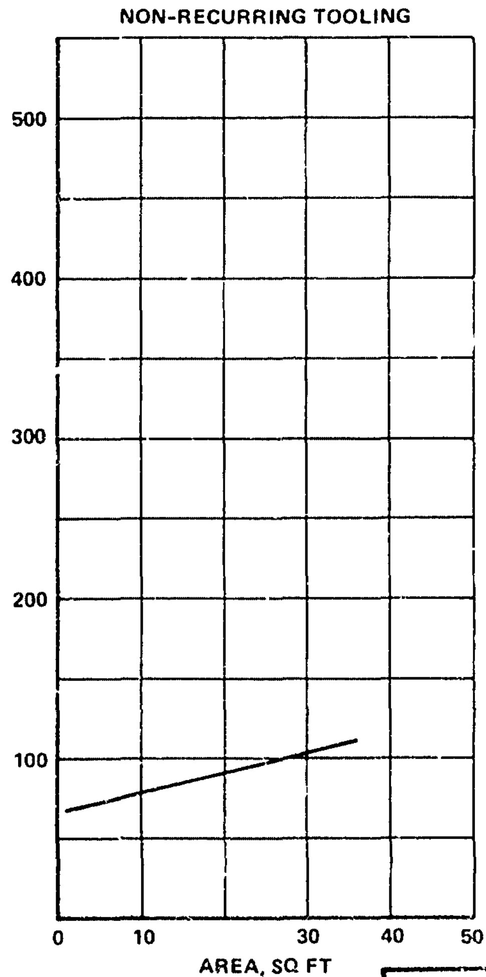
CED—A-23



ALUMINUM BEADED PANEL, LOWEST COST PROCESS

RUBBER PRESS





CED—A-24

(2) FORMED IN "O" OR "W" CONDITION, FINAL TEMPER T62

FORMATS FOR

TITANIUM SHEET-METAL AEROSPACE DISCRETE PARTS

LOWEST COST PROCESSES

FORMATS FOR TITANIUM SHEET-METAL AEROSPACE DISCRETE PARTS LOWEST COST PROCESSES

(1) See ground rules for considerations and limitations.

(2) Step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:

- At room temperature forming $\geq$5T
- At elevated temperature forming $\geq$2T.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:

- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to making a selection of a material or design concept based on the cost of manufacturing.

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as heat treatment, cut-outs, and joggles.

(2) Designer-Influenced Cost Elements (DICE): Includes joggles, cut-outs, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

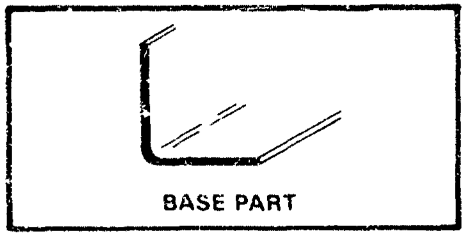
(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

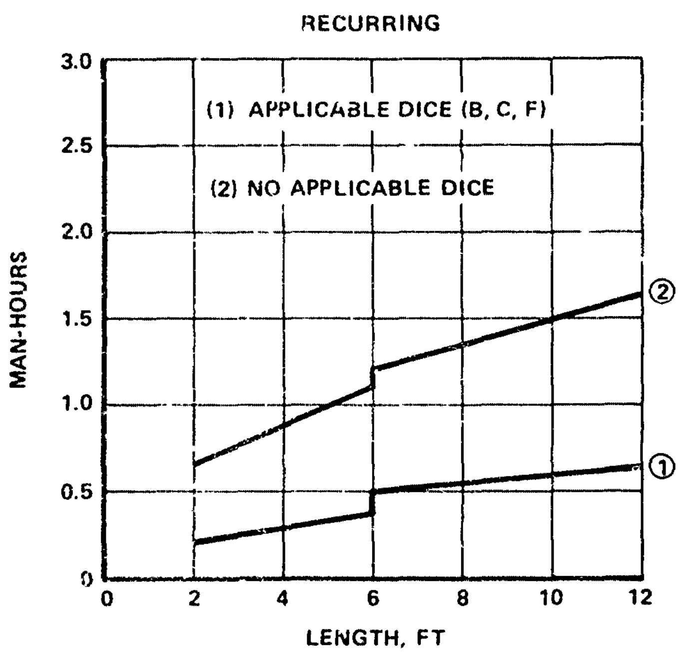
TABLE 5 . FORMATS FOR TITANIUM SHEET-METAL AEROSPACE DISCRETE PARTS

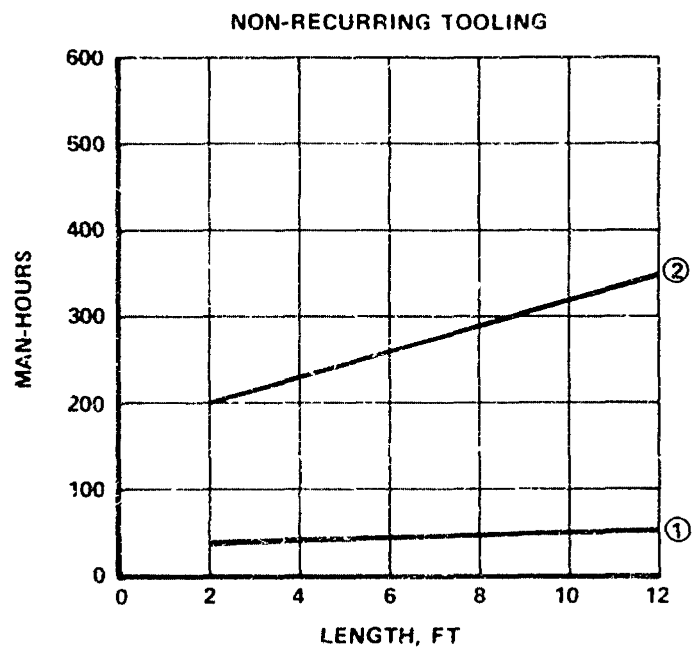
Format Number	Format Title
CED-T-1	Titanium Angle, Straight Member, Lowest Cost Process: Brake Form and Preform/Hot Size
CED-T-2	Titanium Angle, Contoured Member, Lowest Cost Process: Preform/Hot Size
CED-T-3	Titanium Channel, Straight Member, Lowest Cost Process: Brake Form and Preform/Hot Size
CED-T-4	Titanium Channel, Contoured Member, Lowest Cost Process: Brake/Hot Stretch
CED-T-5	Titanium Zee, Straight Member, Lowest Cost Process: Brake Form and Preform/Hot Size
CED-T-6	Titanium Zee, Contoured Member, Lowest Cost Process: Brake/Hot Stretch
CED-T-7	Titanium Cylindrical Curvature Skin, Lowest Cost Process: Farnham Roll
CED-T-8	Ticanium Non-Cylindrical Curvature Skin, Lowest Cost Process: Creep Form
CED-T-9	Titanium Frame, Lowest Cost Process: Hot Press

TITANIUM ANGLE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM AND HOT SIZE







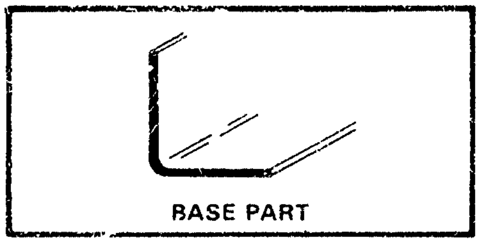
(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t

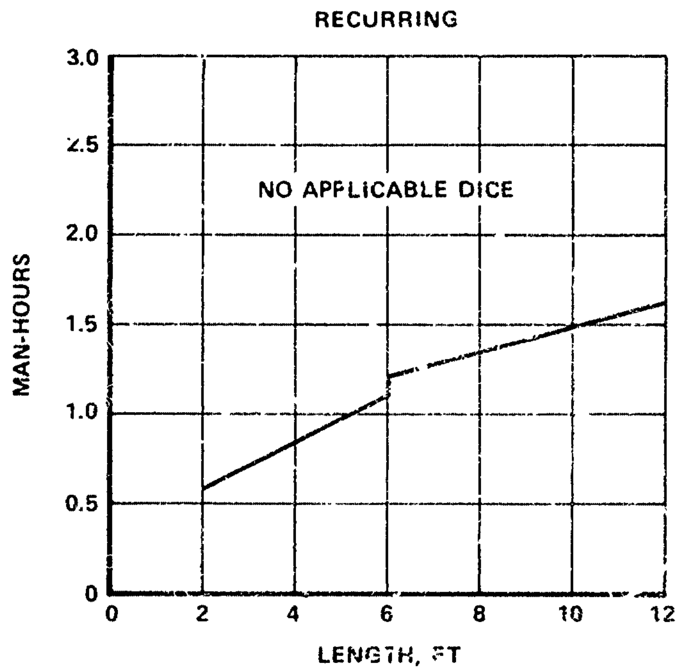
(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

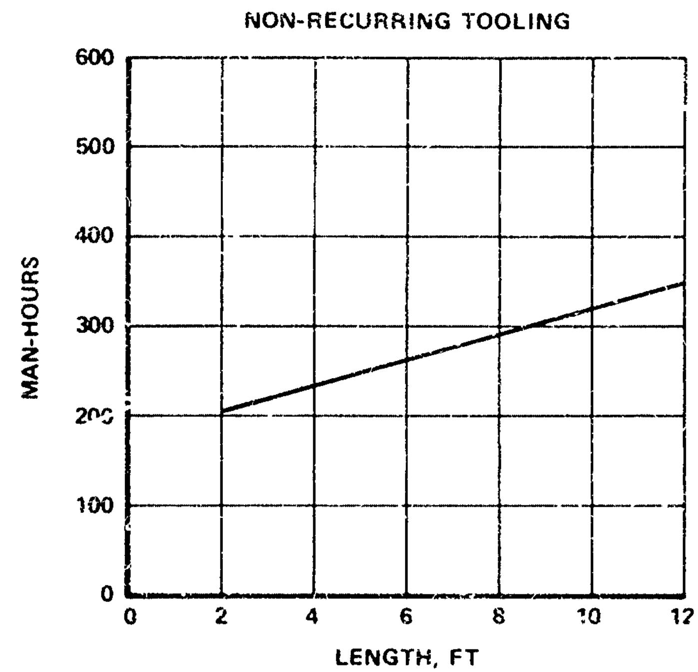
CED—T-1

TITANIUM ANGLE, CONTOURED MEMBER, LOWEST COST PROCESS

PREFORM/HOT SIZE



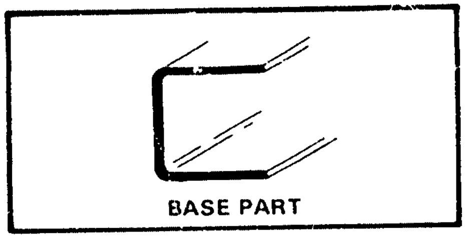


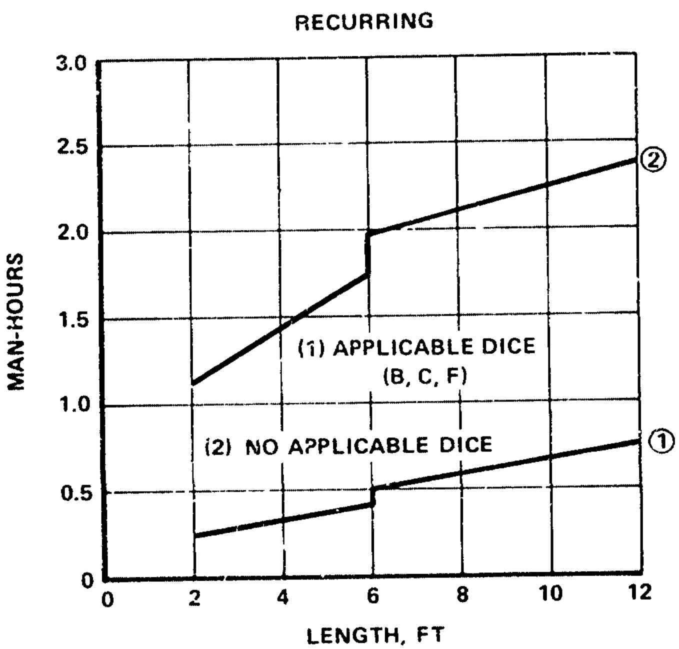


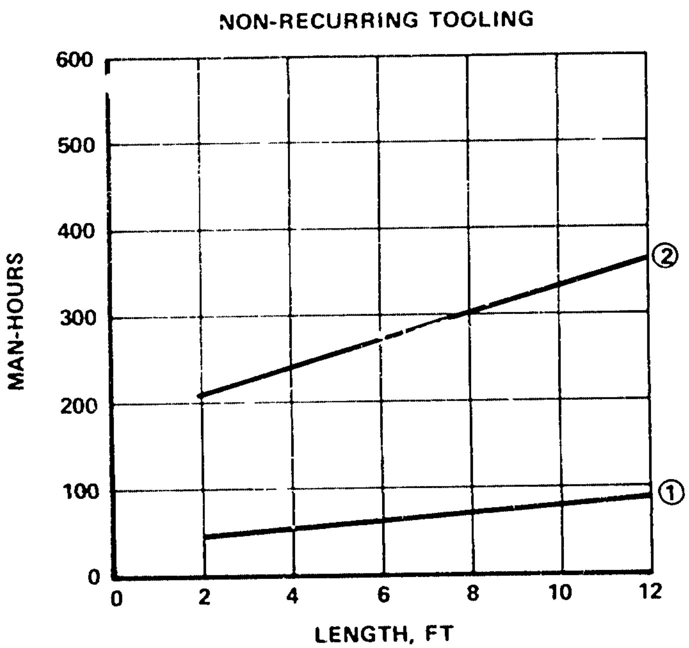
MINIMUM BEND RADIUS = 2t

CED—T-2

TITANIUM CHANNEL, STRAIGHT MEMBER, LOWEST COST PROCESS
BRAKE FORM AND PREFORM/HOT SIZE





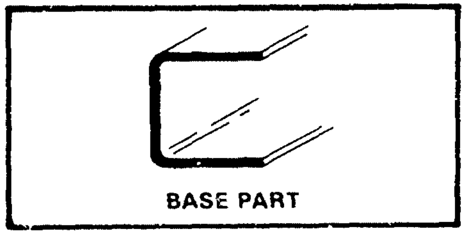


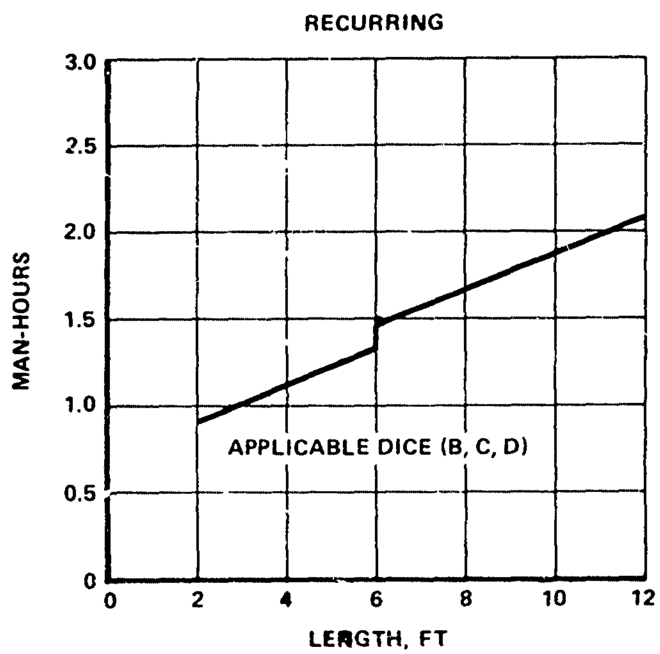
(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t
(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

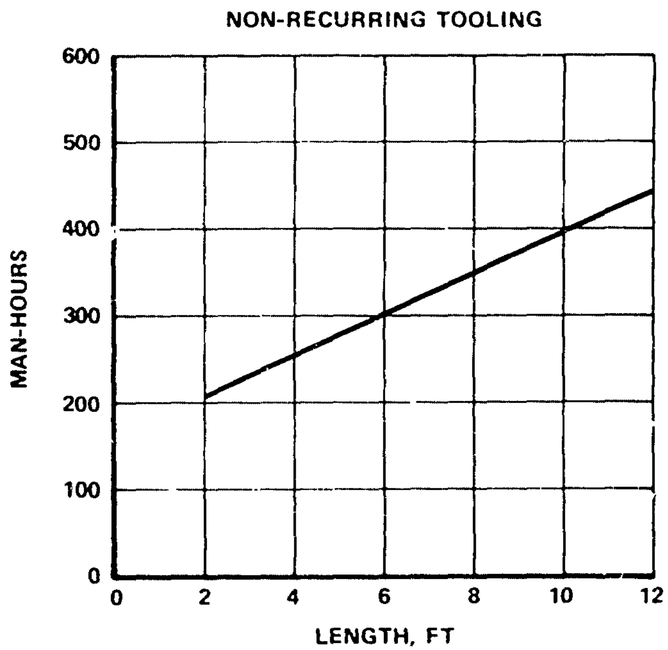
CED—T-3

TITANIUM CHANNEL, CONTOURED MEMBER,* LOWEST COST PROCESS

BRAKE/HOT STRETCH





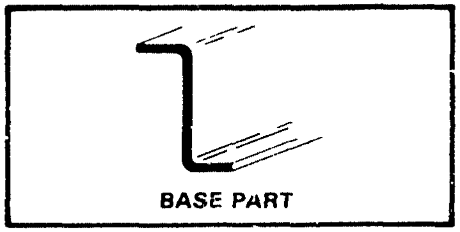


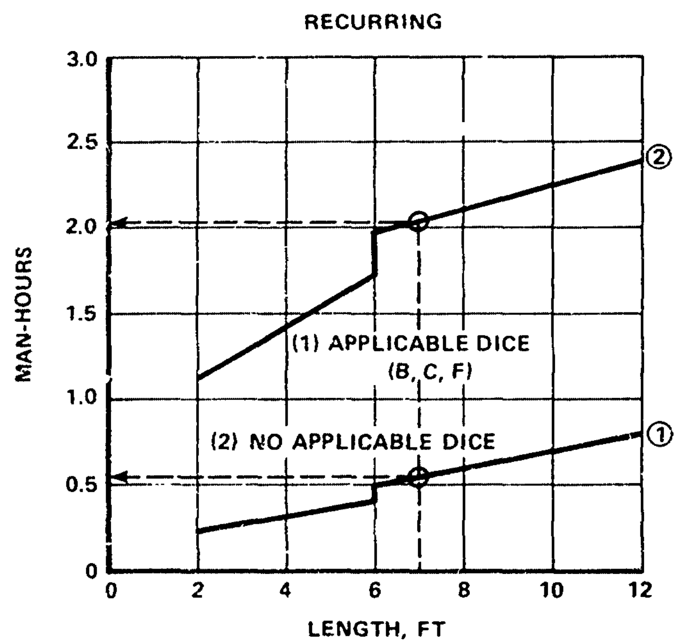
*NO REVERSE CURVATURE

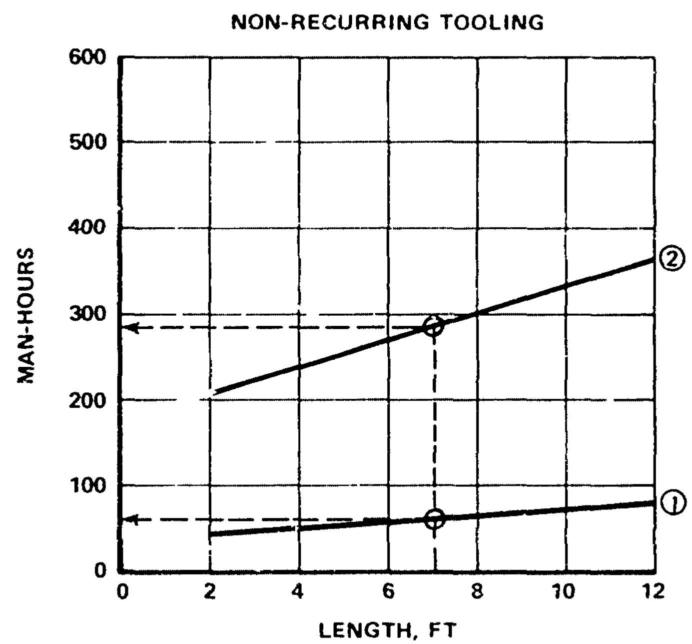
CED—T-4

TITANIUM ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM AND PREFORM/HOT SIZE





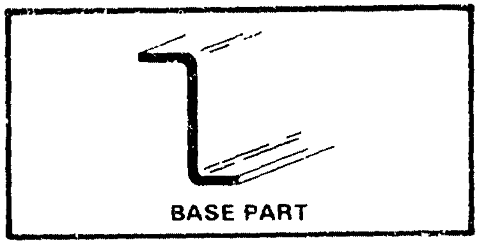


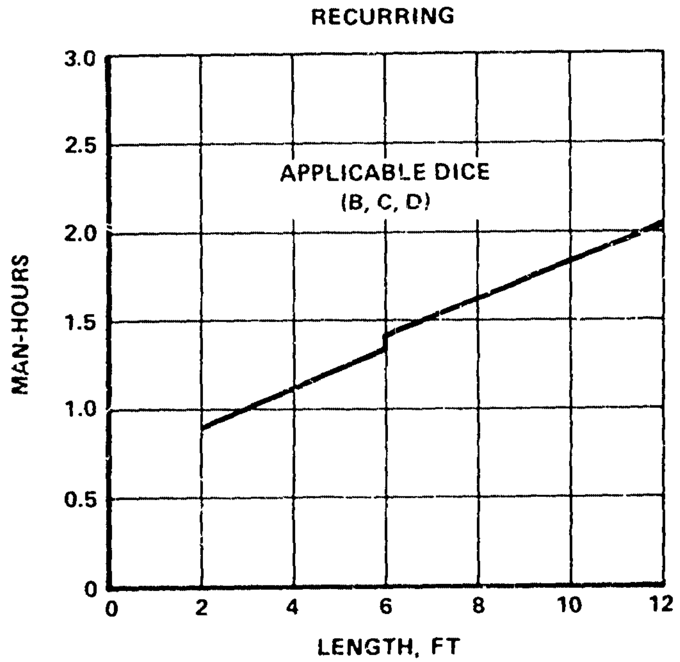
(1) ROOM TEMPERATURE BRAKE FORM, MINIMUM BEND RADIUS = 5t
(2) PREFORM/HOT SIZE, MINIMUM BEND RADIUS = 2t

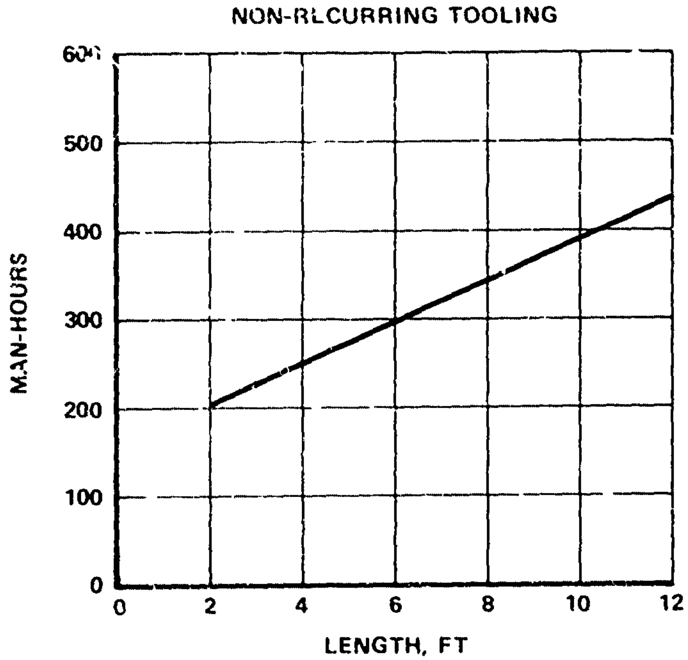
CED—T-5

TITANIUM ZEE, CONTOURED MEMBER,*
LOWEST COST PROCESS

BRAKE/HOT STRETCH







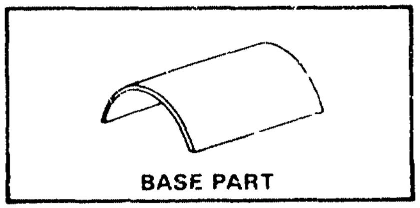
MINIMUM BEND RADIUS = 2t

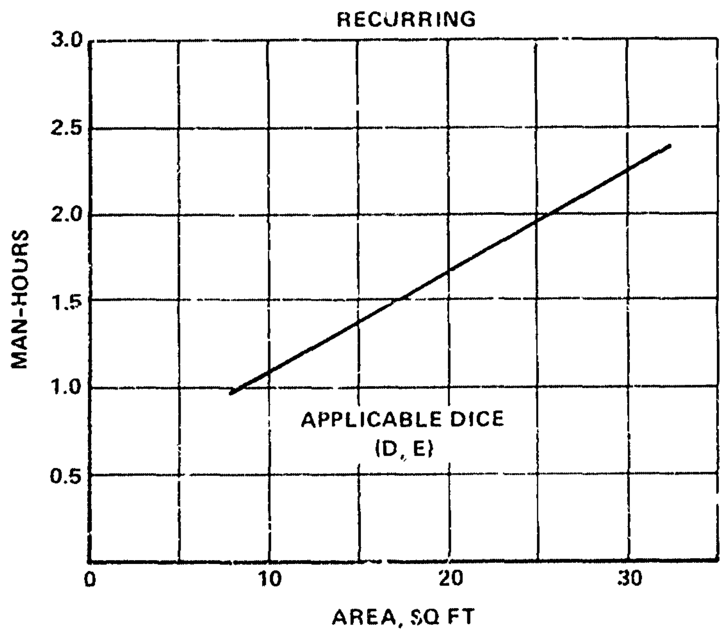
*NO REVERSE CURVATURE

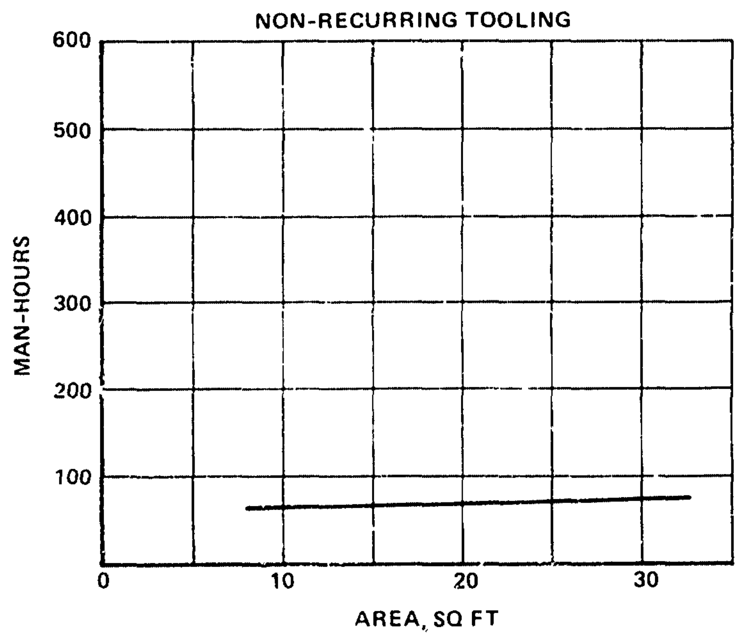
CED—T-6

TITANIUM CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS

FARNHAM ROLL



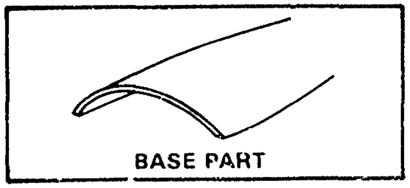


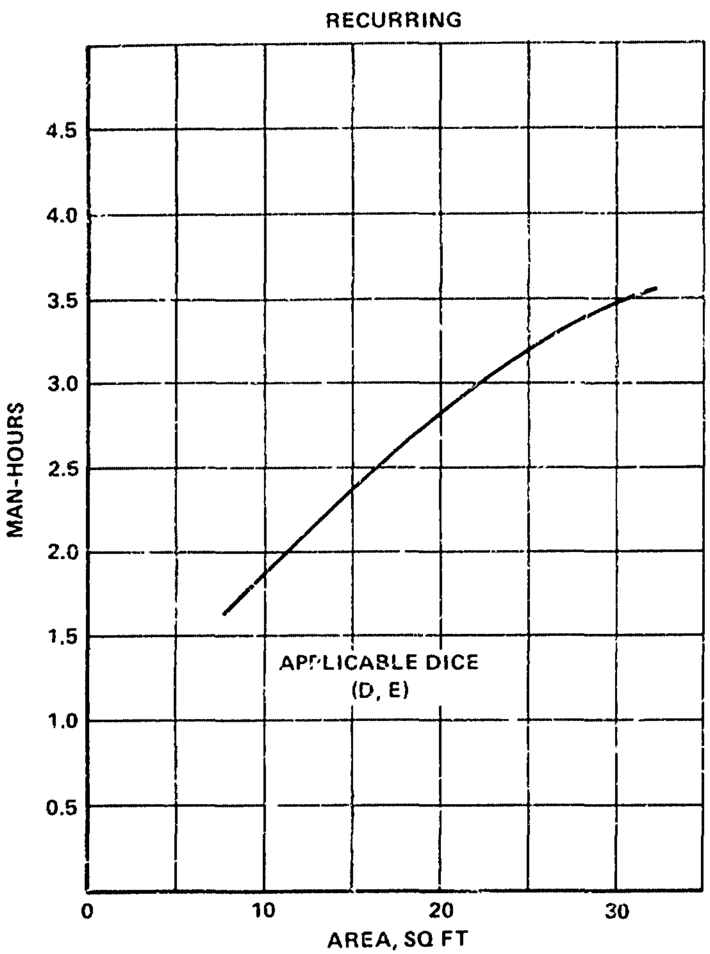


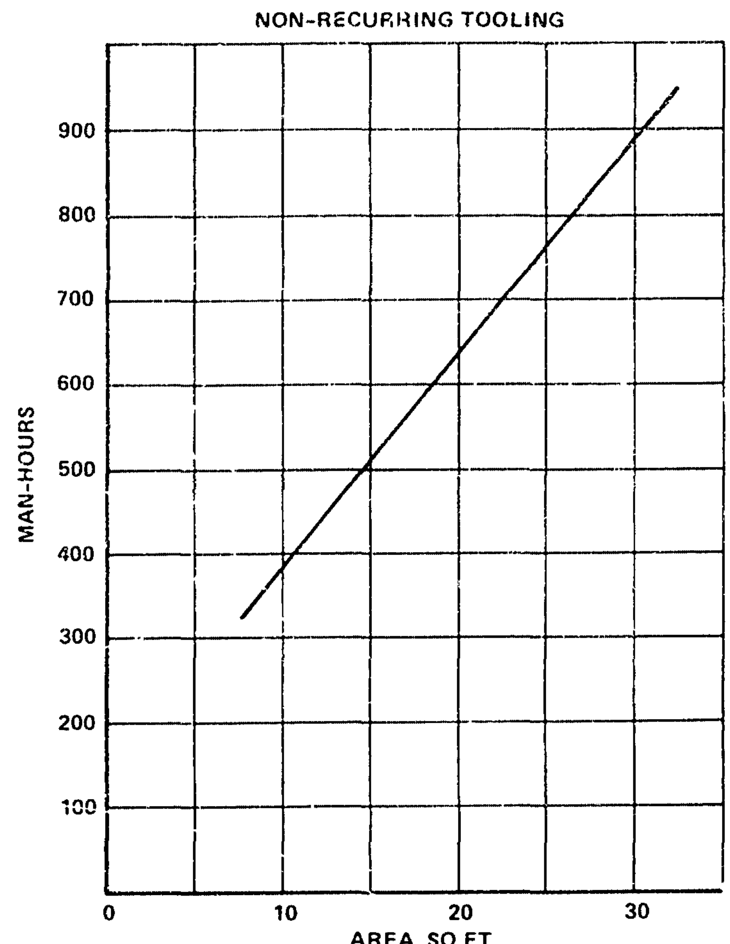
CED—T-7

TITANIUM NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS

CREEP FORM



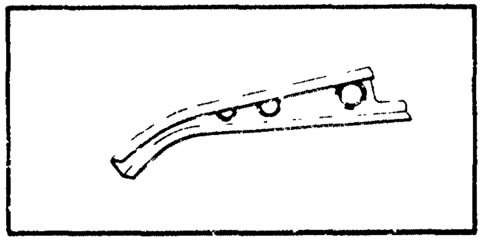


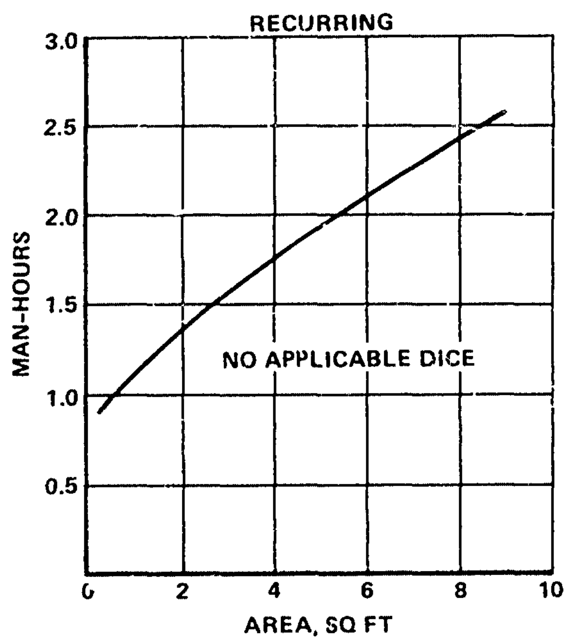


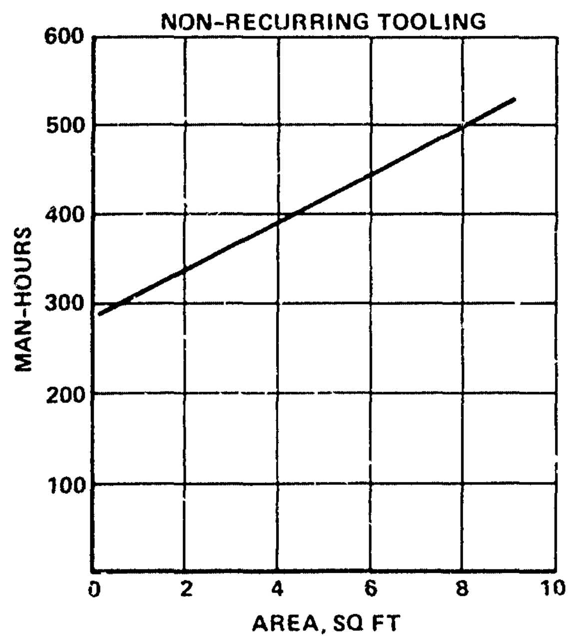
*NO REVERSE CURVES

CED—T-8

TITANIUM FRAME, LOWEST COST PROCESS
HOT PRESS







CED—T-9

FORMATS FOR

STEEL SHEET-METAL AEROSPACE DISCRETE PARTS

LOWEST COST PROCESSES

FORMATS FOR STEEL SHEET-METAL AEROSPACE
DISCRETE PARTS LOWEST COST PROCESSES

(1) See ground rules for considerations and limitations.

(2) Step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:

- At room temperature forming $\geq 5T$
- At elevated temperature forming $\geq 2T$.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:

- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to making a selection of a material or design concept based on the cost of manufacturing.

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as heat treatment, cut-outs, and joggles.

(2) Designer-Influenced Cost Elements (DICE): Includes joggles, cut-outs, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

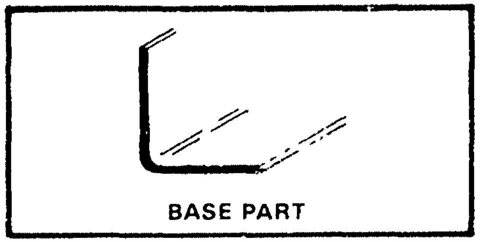
(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

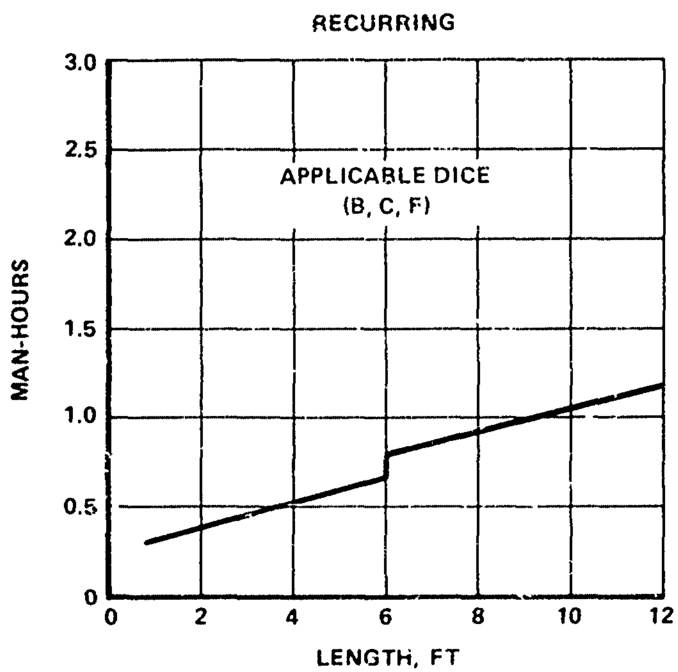
TABLE 5. FORMATS FOR STEEL SHEET-METAL AEROSPACE DISCRETE PARTS

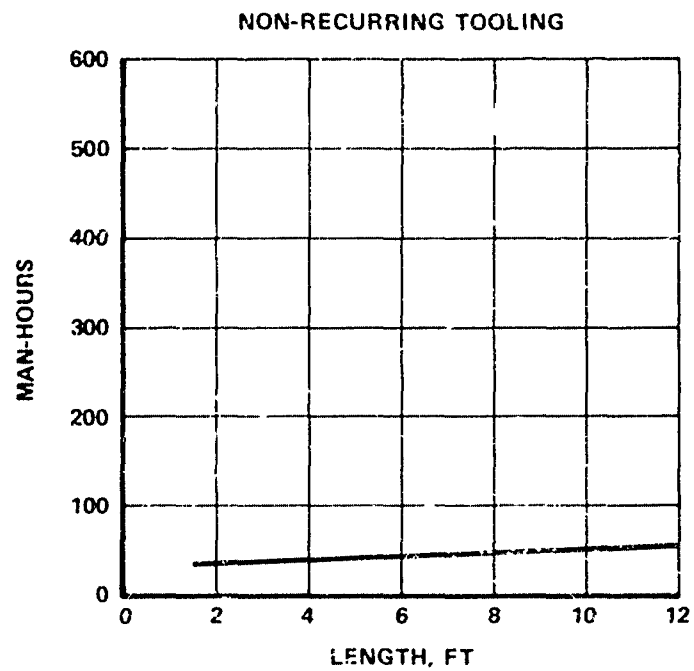
Format Number	Format Title
CED-S-1	Steel Angle, Straight Member, Lowest Cost Process: Brake Form
CED-S-2	Steel Angle, Contoured Member, Lowest Cost Process: Rubber Press
CED-S-3	Steel Channel, Straight Member, Lowest Cost Process: Brake Form
CED-S-4	Steel Channel, Contoured Member. Lowest Cost Process: Rubber Press
CED-S-5	Steel Zee, Straight Member, Lowest Cost Process: Brake Form
CED-S-6	Steel Zee, Cylindrically Contoured Member, Lowest Cost Process: Brake/Roll
CED-S-7	Steel Zee, Non-Cylindrically Contoured Member, Lowest Cost Process: Rubber Press
CED-S-8	Steel Cylindrical Curvature Skin, Lowest Cost Process: Farnham Roll
CED-S-9	Steel Non-Cylindrical Curvature Skin, Lowest Cost Process: Stretch Form
CED-S-10	Steel Frame, Lowest Cost Process: Rubber Press

STEEL ANGLE, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM



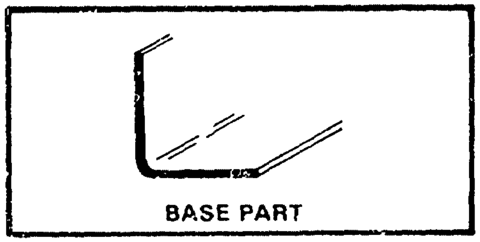


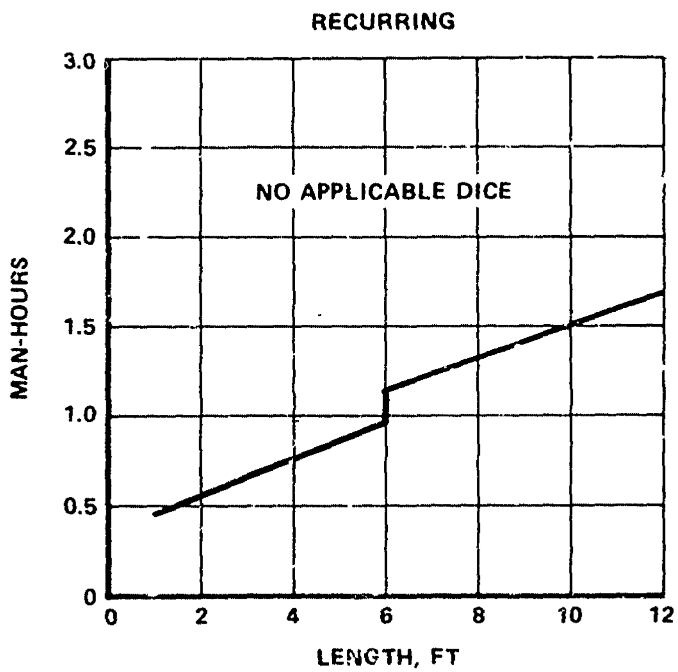


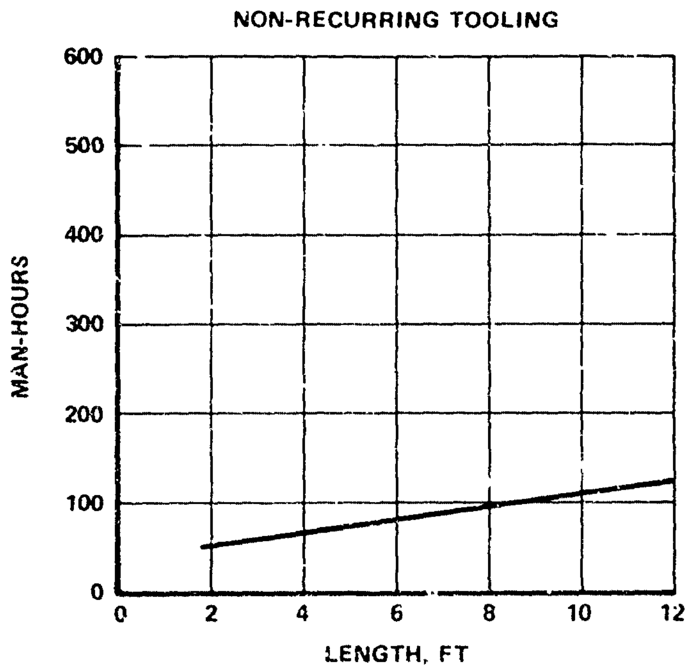
CED—S-1

STEEL ANGLE, CONTOURED MEMBER*, LOWEST COST PROCESS

RUBBER PRESS





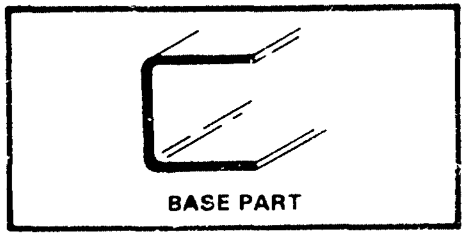


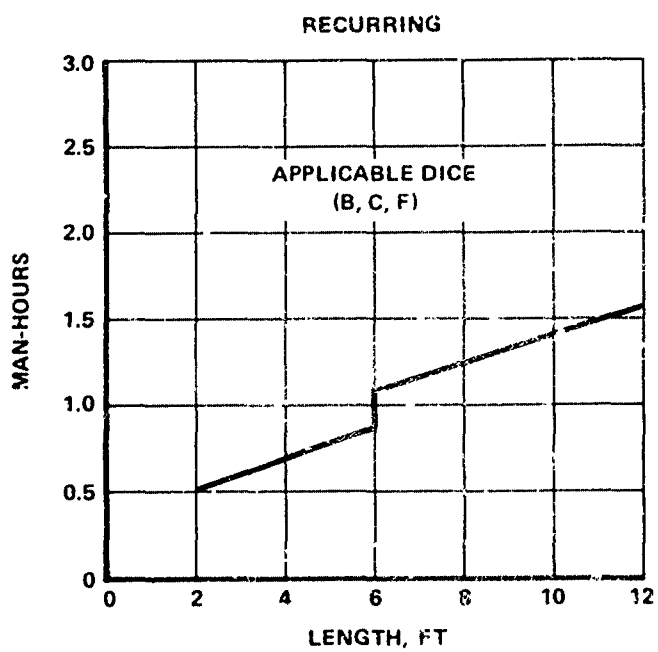
CED—S-2

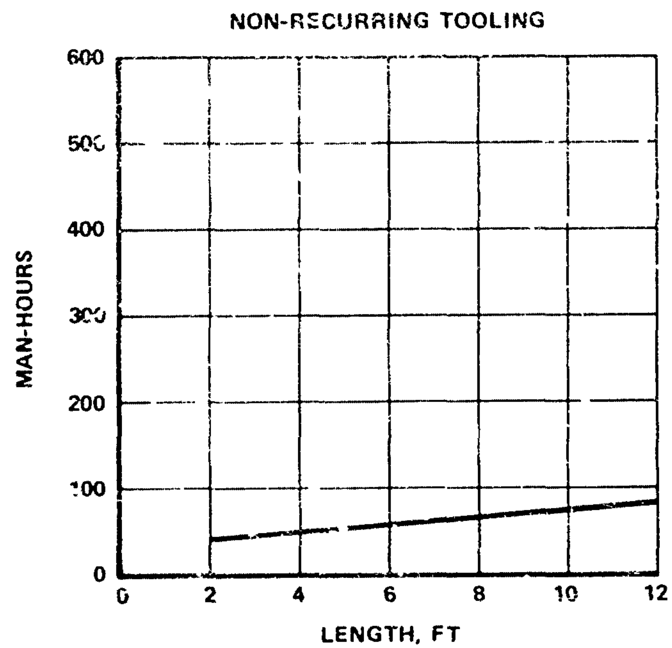
*NO REVERSE CURVES

STEEL CHANNEL, STRAIGHT MEMBER, LOWEST COST PROCESS

BRAKE FORM



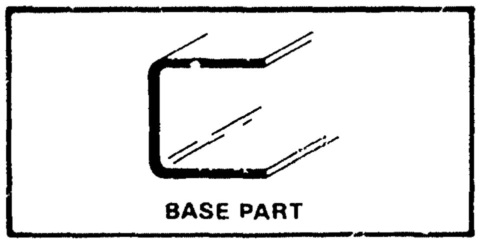


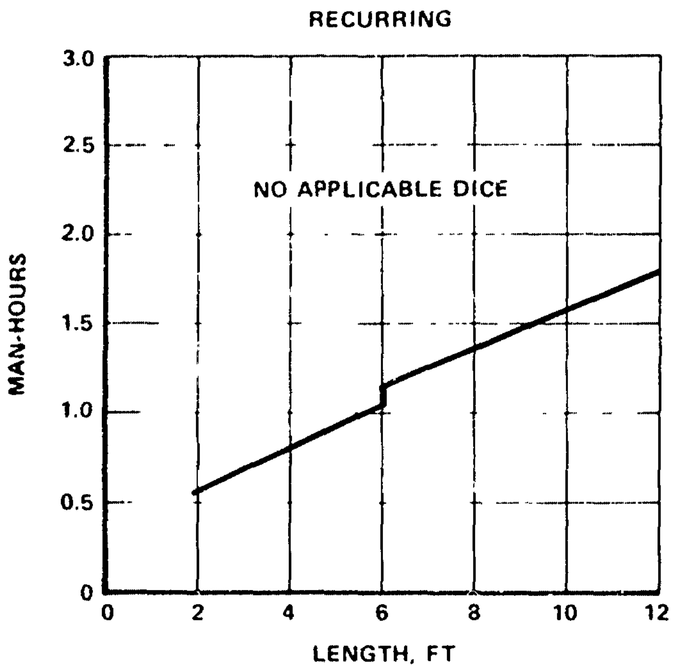


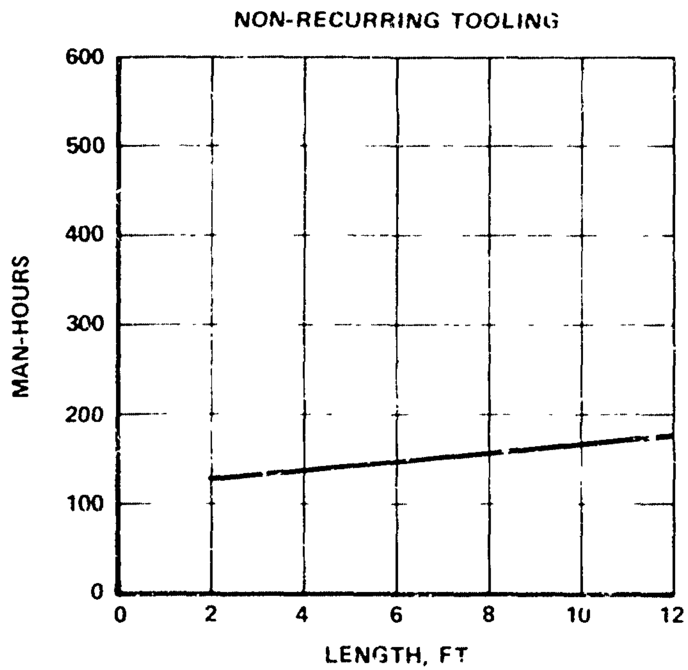
CED—S-3

STEEL CHANNEL, CONTOURED MEMBER*, LOWEST COST PROCESS

RUBBER PRESS





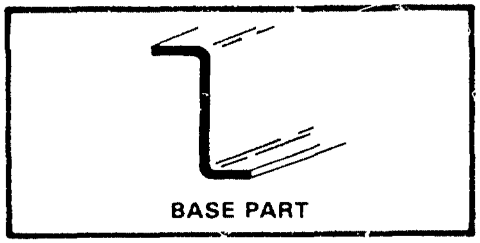


CED—S-4

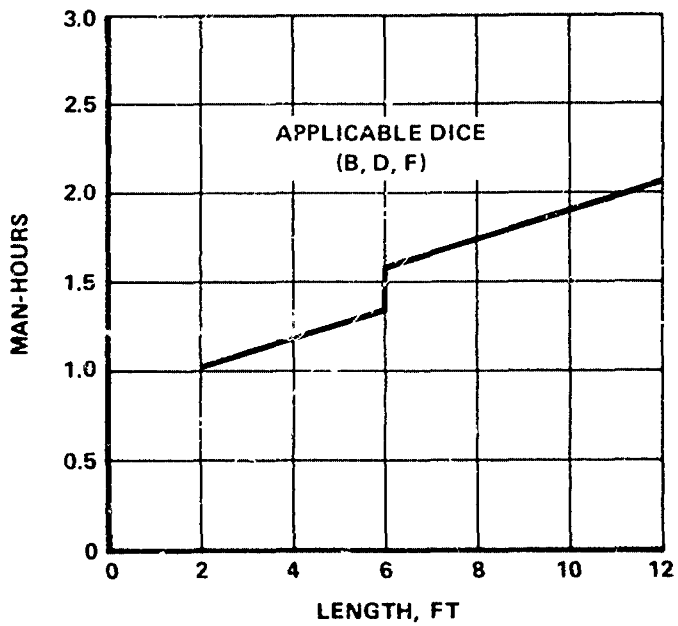
*NO REVERSE CURVES

STEEL ZEE, STRAIGHT MEMBER, LOWEST COST PROCESS

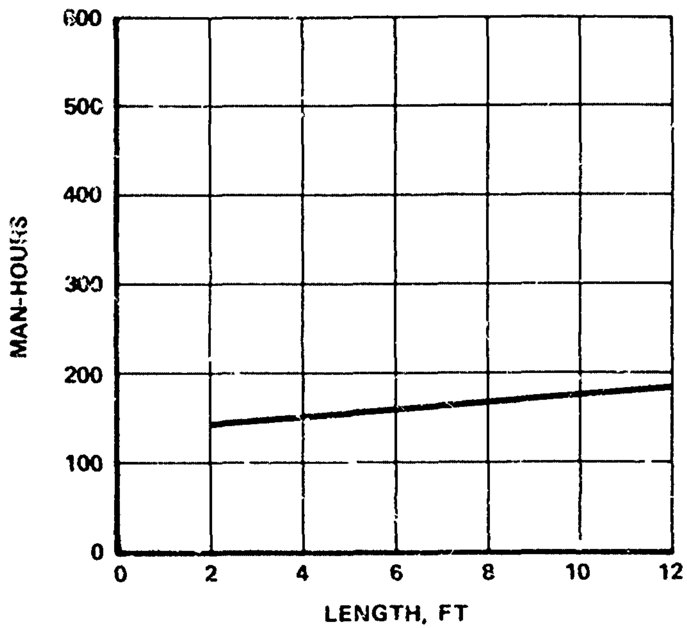
BRAKE FORM



RECURRING



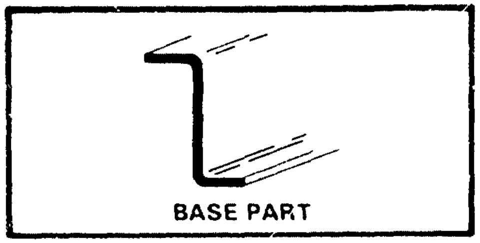
NON-RECURRING TOOLING



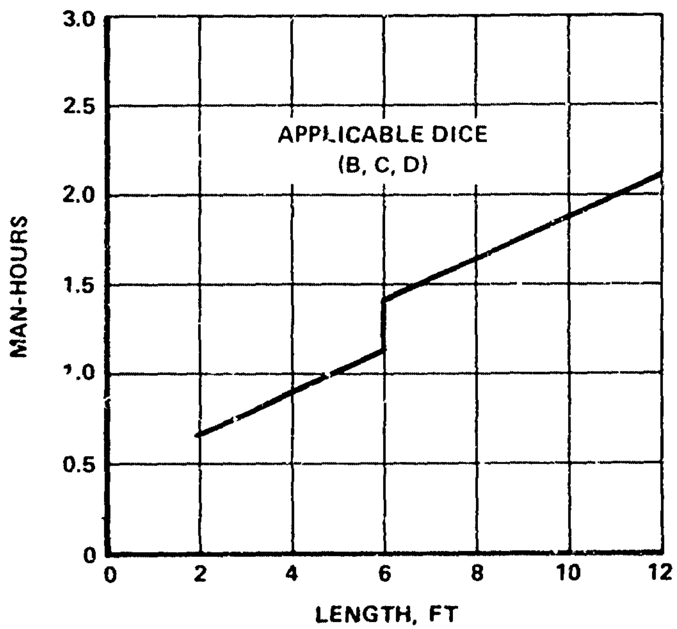
CED—S-5

STEEL ZEE, CYLINDRICALLY CONTOURED MEMBER, LOWEST COST PROCESS

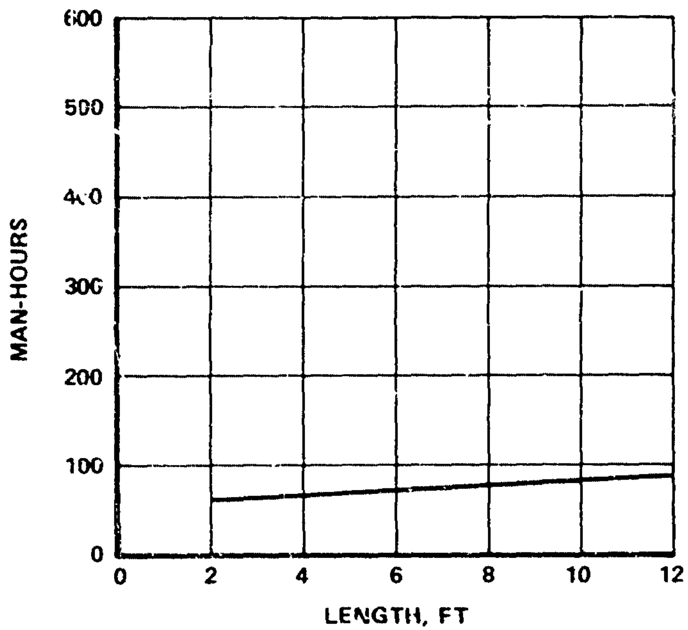
BRAKE/ROLL



RECURRING



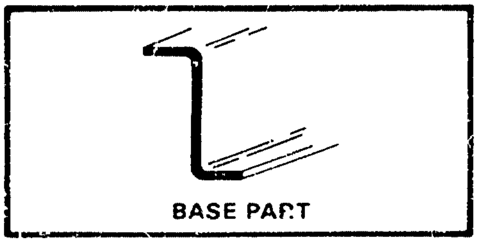
NON-RECURRING TOOLING

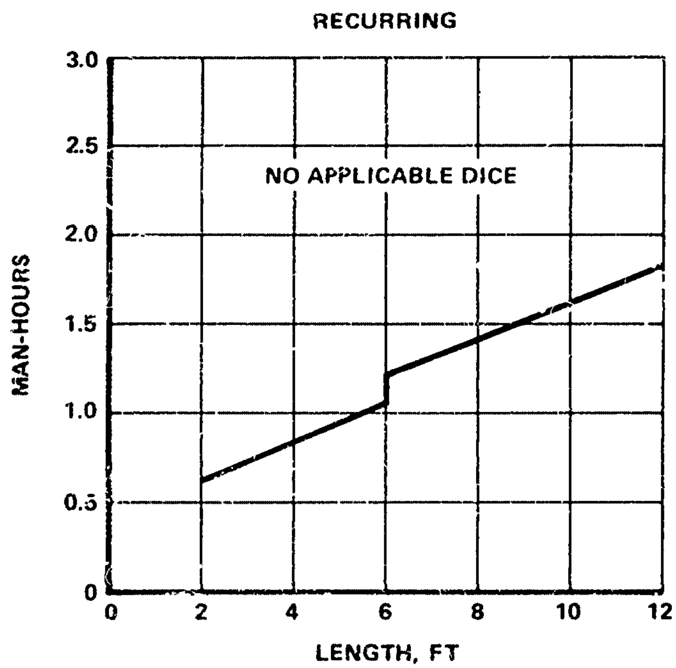


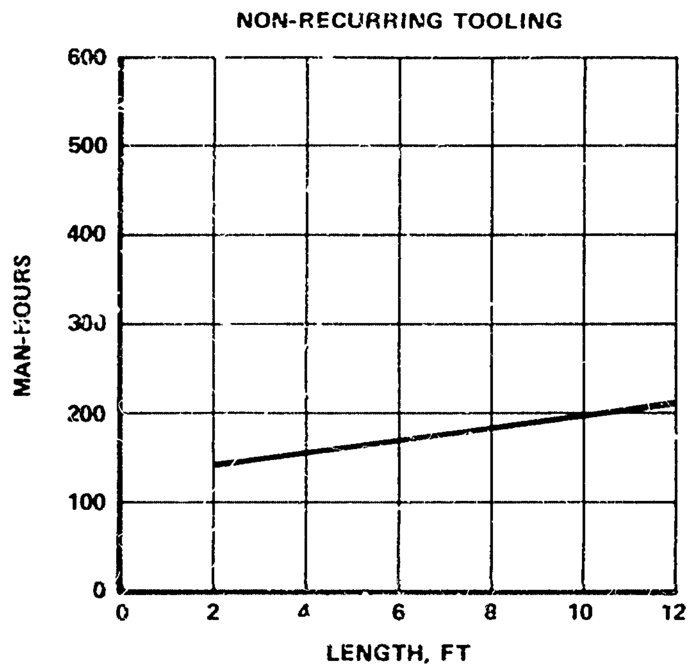
CED—S-6

STEEL NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS

STRETCH FORM





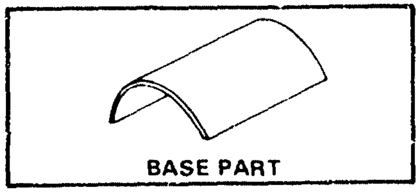


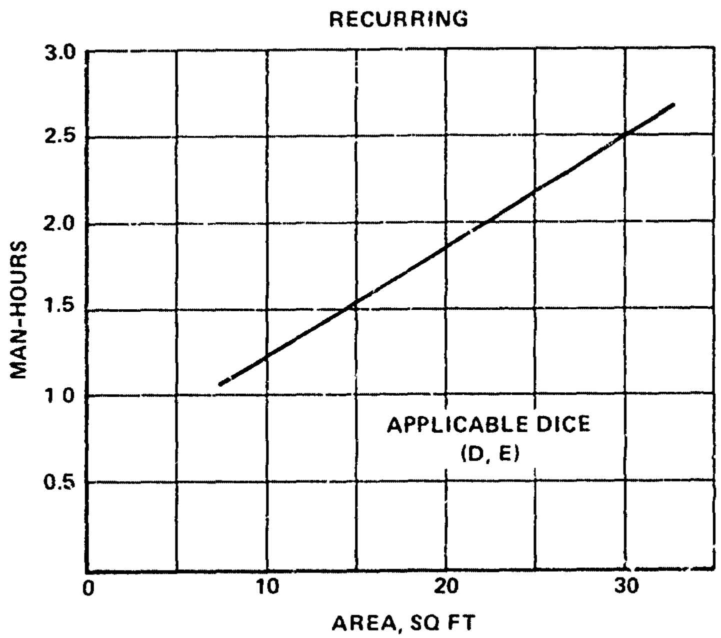
*NO REVERSE CURVES

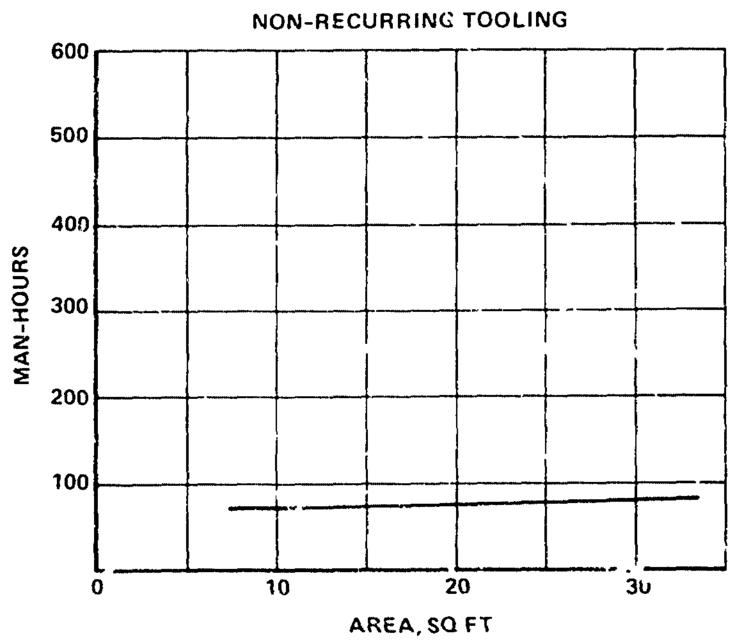
CED—S-7

STEEL CYLINDRICAL CURVATURE SKIN, LOWEST COST PROCESS

FARNHAM ROLL



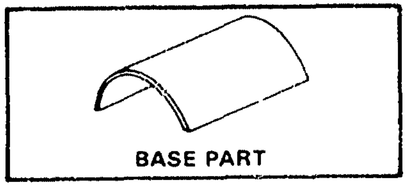


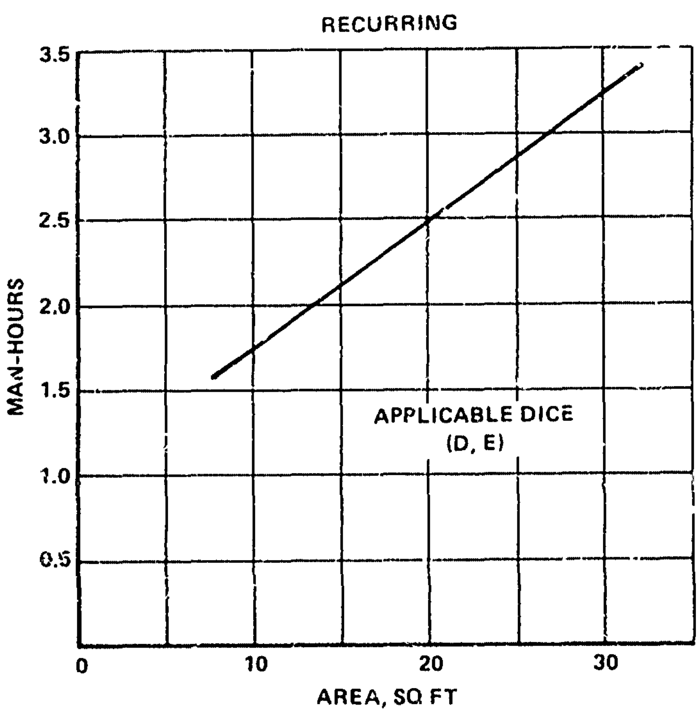


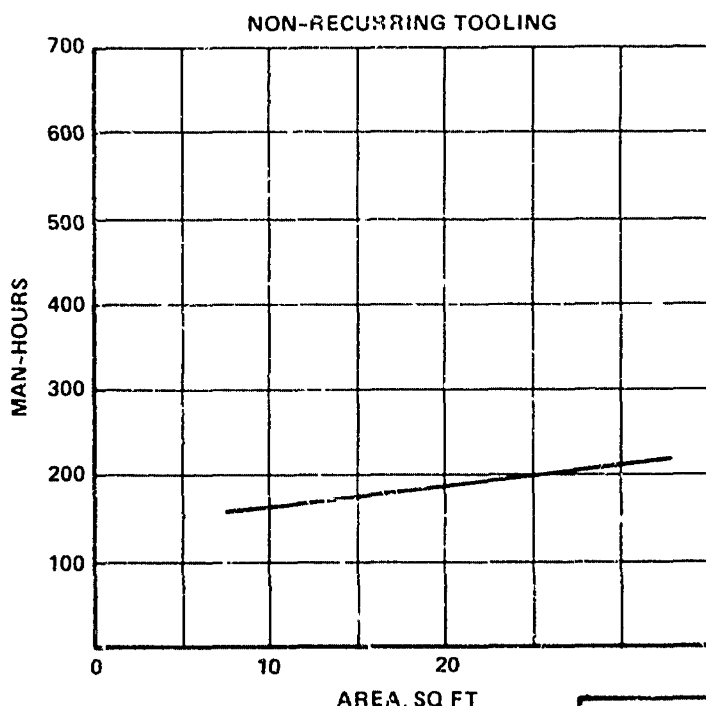
CED—S-8

STEEL NON-CYLINDRICAL CURVATURE SKIN*, LOWEST COST PROCESS

STRETCH FORM



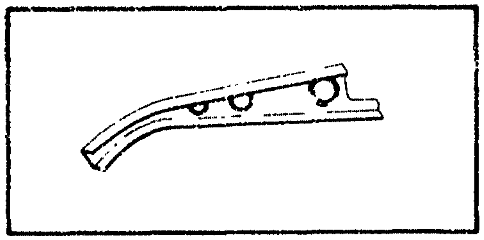


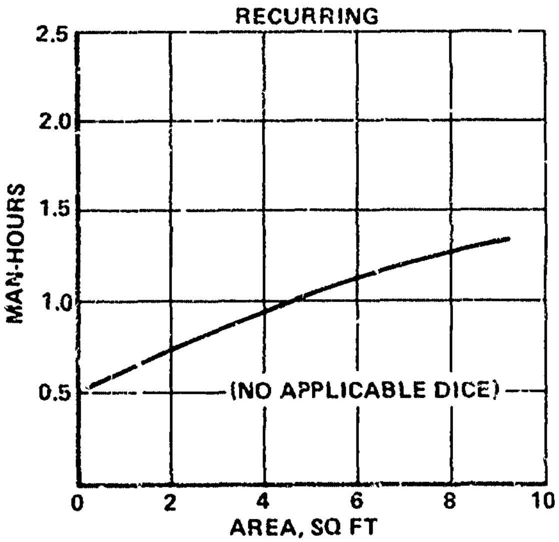


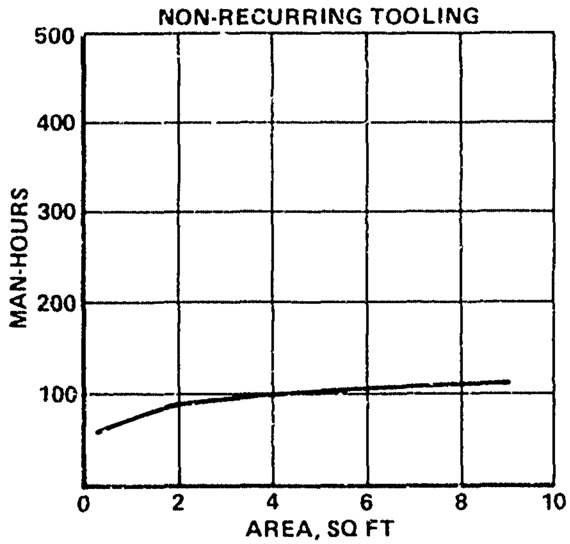
* NO REVERSE CURVES

CED—S-9

STEEL FRAME, LOWEST COST PROCESS
RUBBER PRESS







CED—S-10

FORMATS FOR

DESIGNER-INFLUENCED COST ELEMENTS (DICE)

FOR

SHEET-METAL AEROSPACE DISCRETE PARTS

FORMATS FOR DESIGNER-INFLUENCED COST ELEMENTS (DICE)
FOR SHEET-METAL AEROSPACE DISCRETE PARTS

NOTES RELATING TO SHEET-METAL FORMATS

(1) See ground rules for considerations and limitations.

(2) Step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$5T
- At elevated temperature forming $\geq$2T.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to making a selection of a material or design concept based on the cost of manufacturing.

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as heat treatment, cut-outs, and joggles.

(2) Designer-Influenced Cost Elements (DICE): Includes joggles, cut-outs, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 7. FORMATS FOR DESIGNER-INFLUENCED COST ELEMENTS (DICE) IN SHEET METAL DISCRETE PART DESIGN

Format Number	Format Title
	COST-DRIVER EFFECTS (CDE) FORMAT
DICE-0	Guide to Designer-Influenced Cost Elements (DICE)
	COST-ESTIMATING DATA (CED) FORMATS
DICE-1	Sheet-Metal Aerospace Discrete Parts: DICE Man-Hours
DICE-2	Sheet-Metal Lineal Parts: Joggle Recurring Cost
DICE-3	Sheet-Metal Aerospace Discrete Parts: Flanged Hole Recurring Cost
DICE-4	Aluminum: Stack Rout Prior to Forming
DICE-5	Aluminum Lineal Parts: Trim After Forming
DICE-6	Aluminum: Solution Heat Treat and Age to T62
DICE-7	Aluminum: Artificial Age to T81
DICE-8	Steel: Stack Mill Prior to Forming
DICE-9	Steel Lineal Parts: Trim After Forming
DICE-10	Steel Panels: Trim After Forming
DICE-11	Titanium: Stack Mill Prior to Forming
DICE-12	Titanium Lineal Parts: Trim After Forming
DICE-13	Titanium Panels: Trim After Forming

GUIDE TO DESIGNER INFLUENCED COST ELEMENTS (DICE)

MATERIAL	DESIGNER INFLUENCED COST ELEMENTS / BASE PART MANUFACTURING METHOD	STANDARD JOGGLE	FLANGED HOLES	BEADS	HEAT TREATMENT	SPECIAL FINISH	SPECIAL TOLERANCE	LINEAL TRIM	END TRIM	CUTOUTS W/O FLANGES
ALUMINUM	BRAKE FORM	L	L	X	H	L	H	L	L	L
	BRAKE/BUFFALO ROLL	L	L	X	H	L	H	A	L	A
	BRAKE STRETCH	L	L	X	H	L	N	A	A	A
	DIE FORM	N	N	N	N	L	N	L	L	L
	DROP HAMMER	N	N	N	L	L	H	L	X	A
	FARNHAM ROLL	X	L	X	L	L	H	L	X	A
	ROUTED FLAT SHEET	X	L	X	L	L	H	L	X	L
	RUBBER PRESS	N	N	H	N	L	A	L	L	L
	STRETCH FORM	X	L	A	N	L	N	A	X	A
	YODER ROLL	L	L	X	H	L	H	A	A	A
	YODER STRETCH	L	L	H	N	L	N	A	L	A
TITANIUM	BRAKE FORM R.T.	A	L	X	X	L	H	H	H	L
	R.T. BRAKE/HOT STRETCH*	A	L	X	X	L	L	H	H	H
	CREEP FORM*	X	L	X	X	L	L	H	H	H
	FARNHAM ROLL	X	L	X	X	L	H	H	H	H
	HOT PRESS*	N	L	N	X	L	L	N	N	L
	PREFORM/HOT SIZE*	N	L	N	X	L	L	N	N	L
STEEL	BRAKE AND BUFFALO ROLL	A	L	X	N	L	H	H	A	L
	BRAKE FORM R.T.	A	L	X	N	L	H	L	L	L
	BRAKE/R.T. STRETCH	A	L	X	N	L	A	H	L	A
	FARNHAM ROLL	X	L	X	N	L	H	H	L	A
	RUBBER PRESS	N	N	N	N	L	A	L	L	L
	STRETCH FORM	X	L	X	N	L	A	H	A	L

LEGEND

RATING	
X	NOT APPLICABLE
N	NO ADDITIONAL COST INCL IN BASE PART COST
L	LOW ADDITIONAL COST
A	AVERAGE ADDITIONAL COST
H	HIGH ADDITIONAL COST

Percentage Cost Ranges For Above

- L Up to 10%
- A 10–30%
- H Above 30%

*Denotes one or more elevated temperature processing steps

SHEET-METAL AEROSPACE DISCRETE PARTS

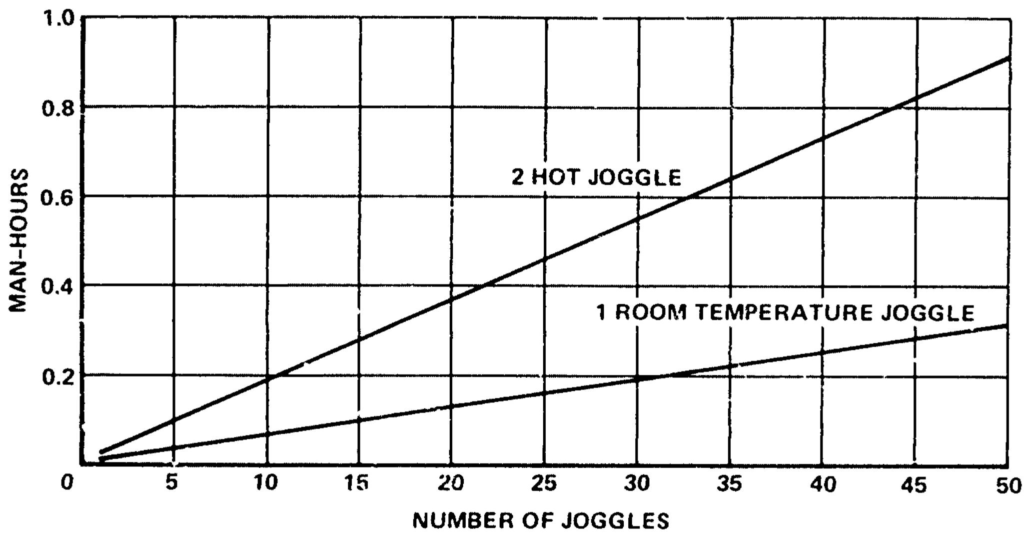
DICE MAN-HOURS

DICE		ALUMINUM 2024	STEEL PH15-7Mo	TITANIUM 6Al-4V
A	HEAT TREATMENT[1]	T62: 0.8 X BASE PART COST T81: 0.1 X BASE PART COST	NOT APPLICABLE	NOT APPLICABLE
B	STANDARD JOGGLE	0.008 + (0.006 X N*)	0.008 + (0.006 X N) COLD 0.011 + (0.018 X N) HOT	0.011 + (0.018 X N)
C	STANDARD FLANGED HOLE	0.010 + (0.010 X N*)	0.010 + (0.010 X N)	0.010 + (0.010 X N)
D	SPECIAL LINEAL TRIM	PER FOOT: 0.021 MAN-HOURS**	PER FOOT: 0.049 MAN-HOURS**	PER FOOT: 0.061 MAN-HOURS**
E	STANDARD CUTOUT	0.024 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER	0.036 MAN-HOURS PER FOOT OF PERIMETER

*N = NUMBER OF JOGGLES OR FLANGED HOLES.
**COST INCLUDES AMORTIZED TOOLING, AMORTIZED OVER 200 UNITS
1: THIS IS A COMPOSITE FACTOR FOR ALL SHAPES AND SIZES.
FOR MORE DETAILS SEE DICE 7 OR DICE 8.

DICE-1

SHEET-METAL LINEAL PARTS—JOGGLE RECURRING COST

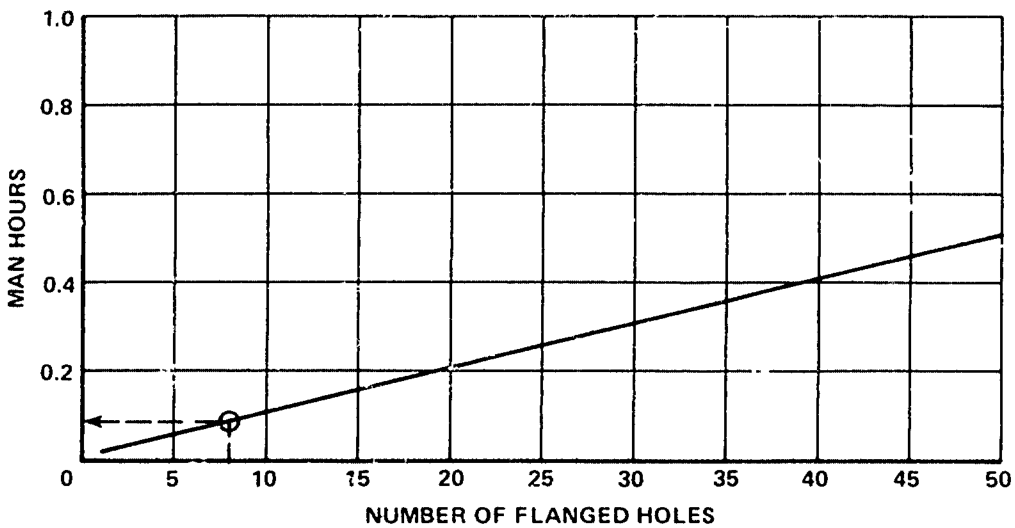


1 USED FOR ALUMINUM AND STEEL PARTS
2 USED FOR TITANIUM PARTS

DICE-2

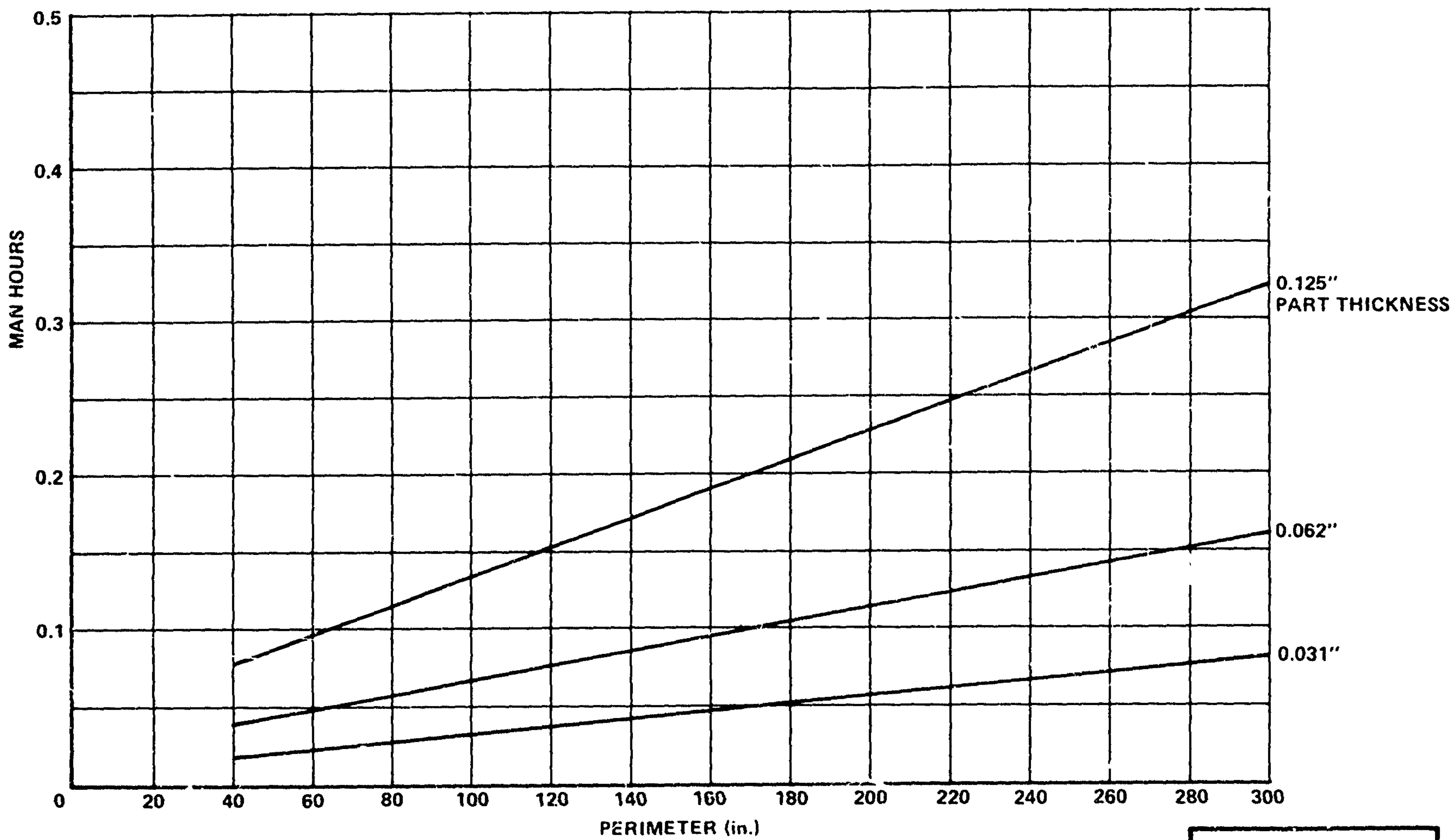
SHEET-METAL AEROSPACE DISCRETE PARTS—FLANGED HOLE RECURRING COST

ALUMINUM TITANIUM AND STEEL



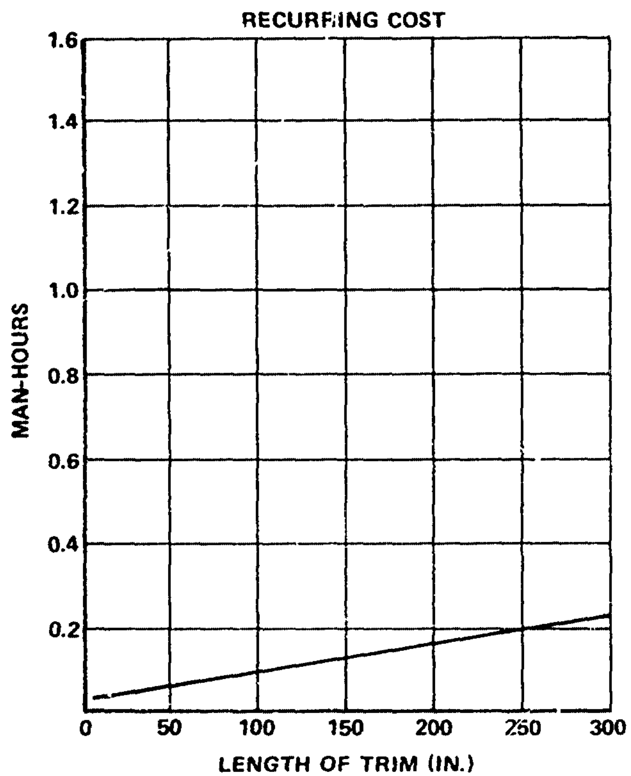
DICE-3

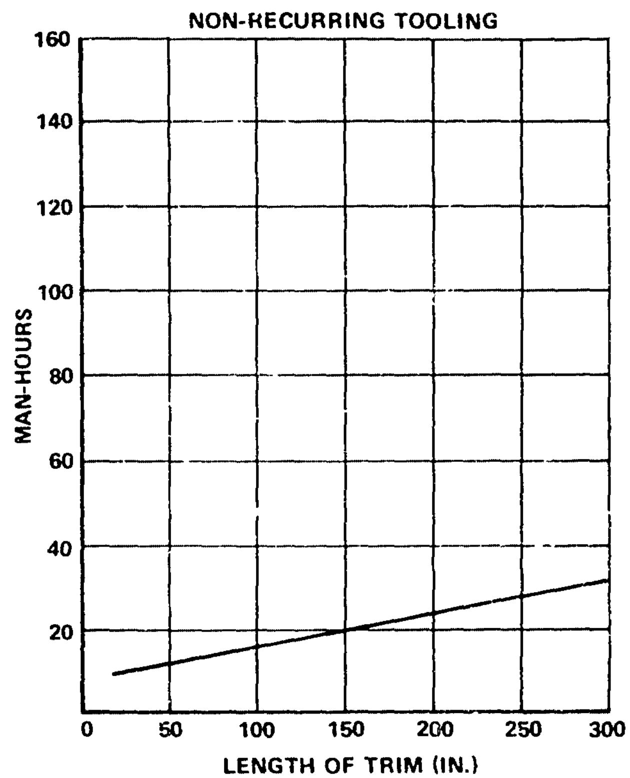
ALUMINUM STACK ROUT PRIOR TO FORMING



DICE-4

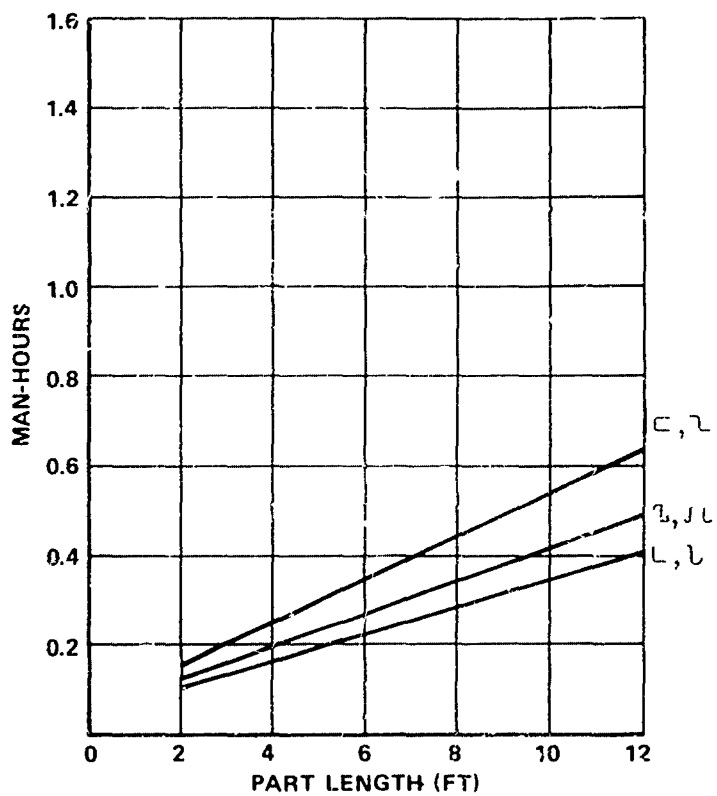
ALUMINUM LINEAL PARTS
TRIM AFTER FORMING





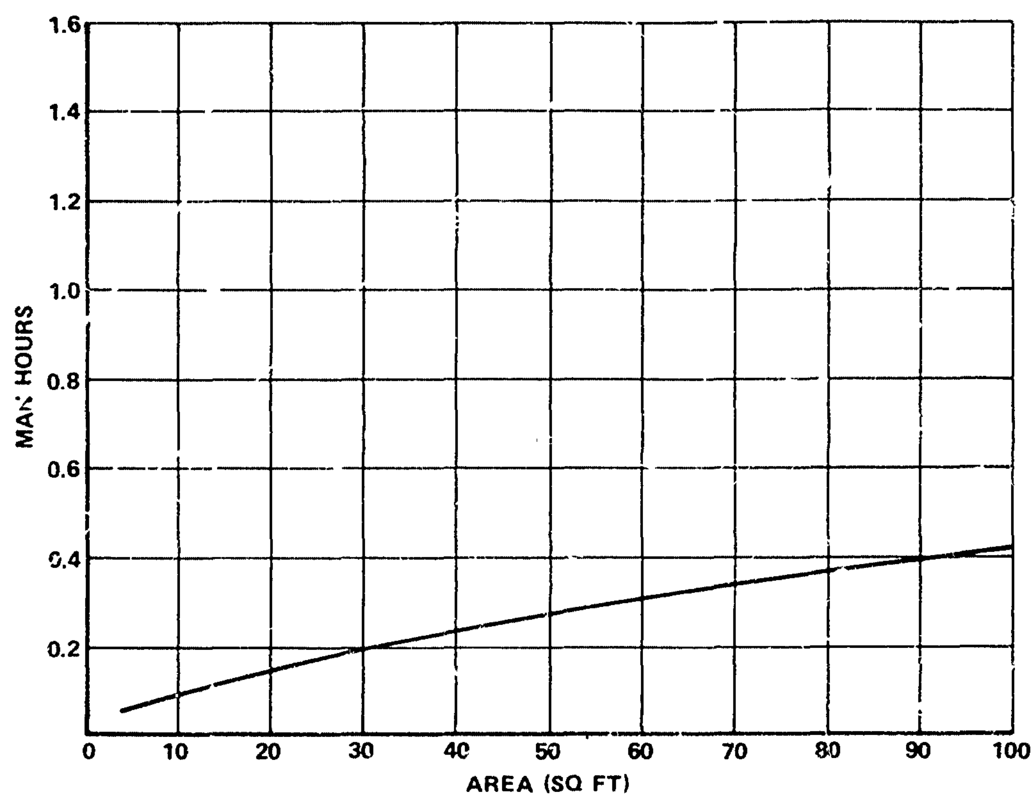
DICE-5

ALUMINUM, SOLUTION HEAT TREAT AND AGE TO T62



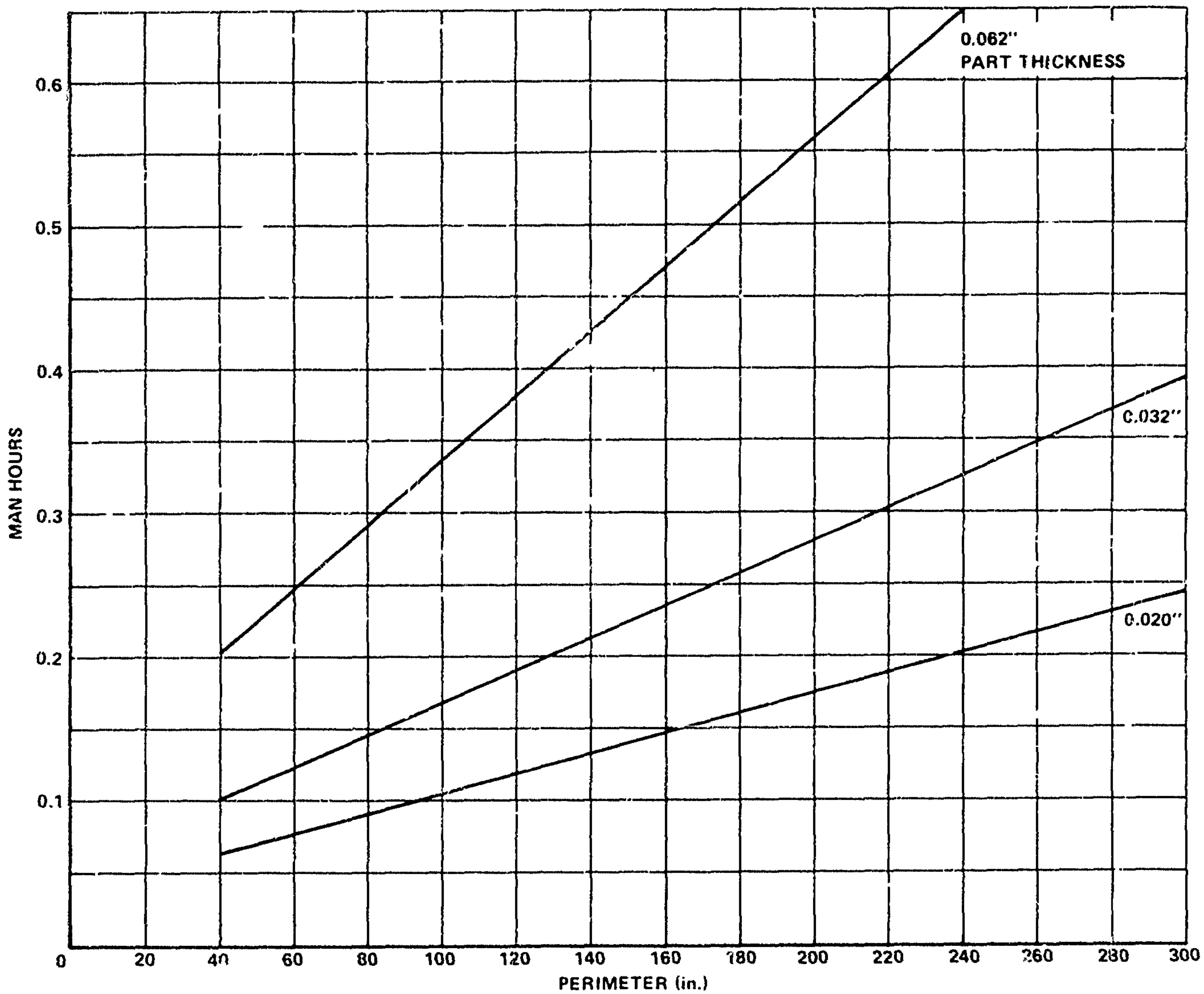
DICE-6

ALUMINUM, ARTIFICIAL AGE TO T81



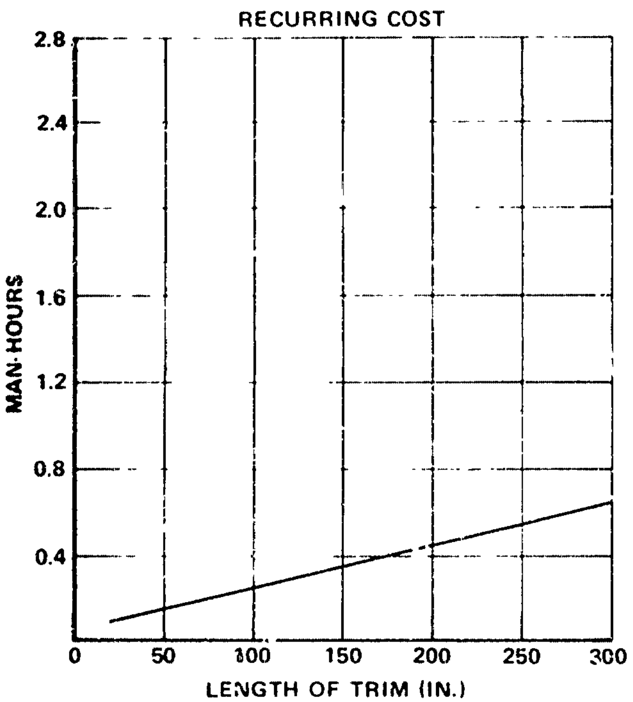
DICE-7

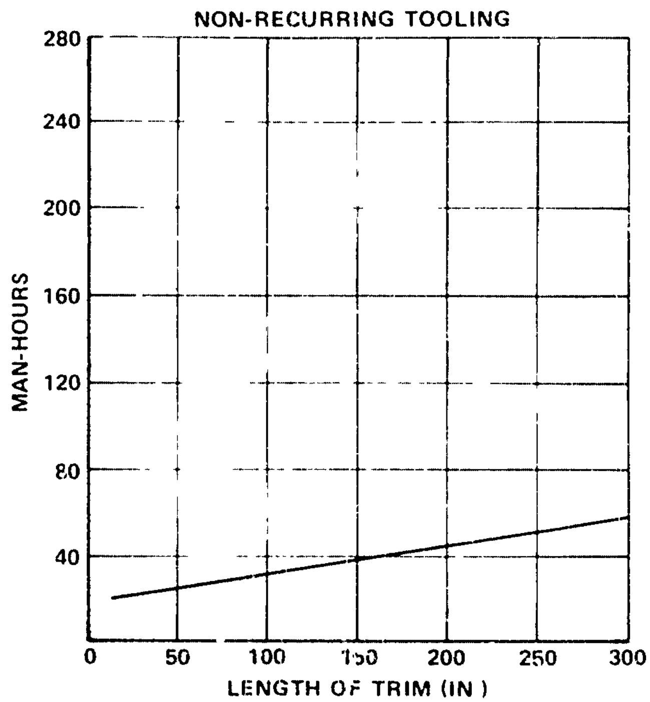
STEEL STACK MILL PRIOR TO FORMING



DICE-8

STEEL LINEAL PARTS
TRIM AFTER FORMING

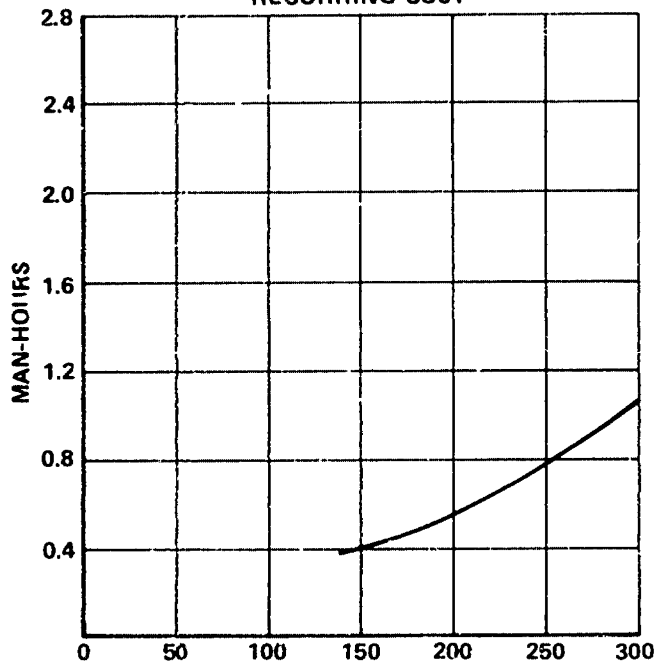




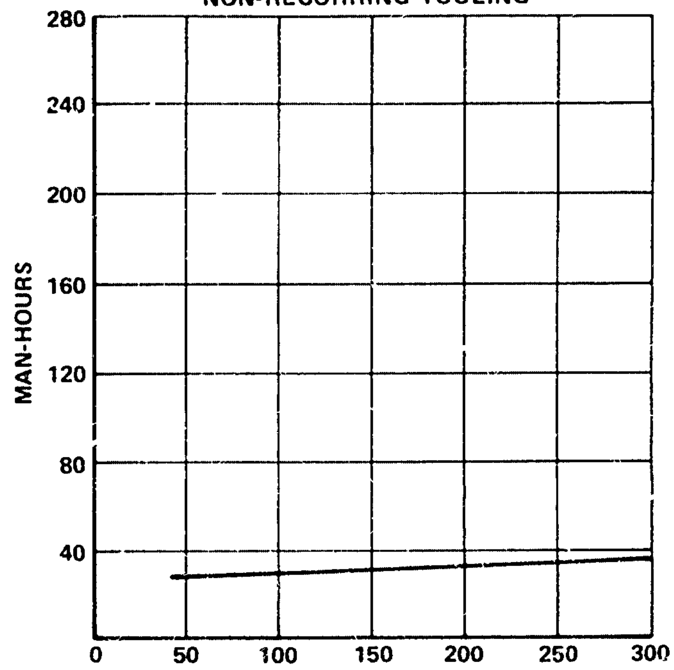
DICE-9

STEEL PANELS
TRIM AFTER FORMING

RECURRING COST

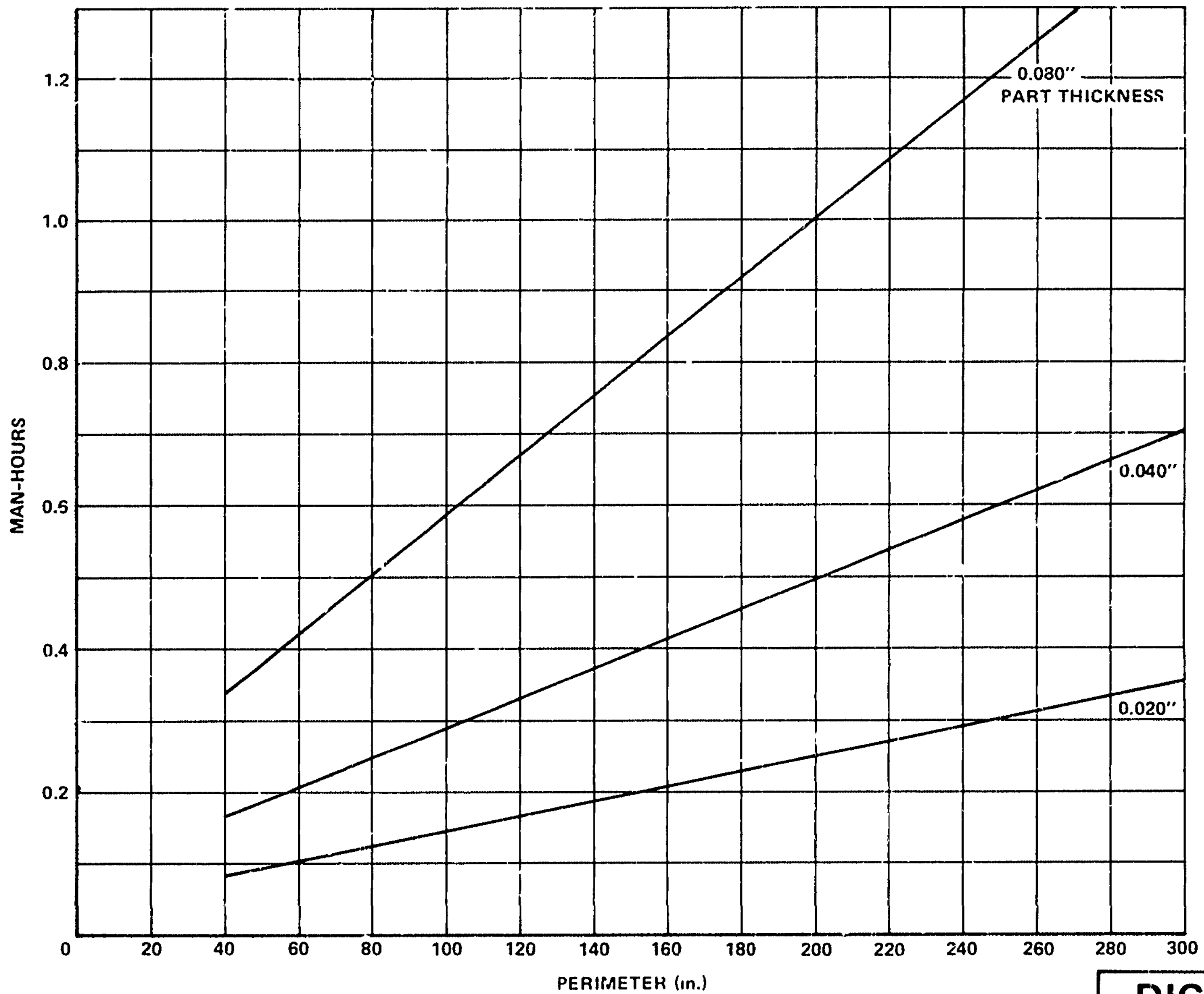


NON-RECURRING TOOLING



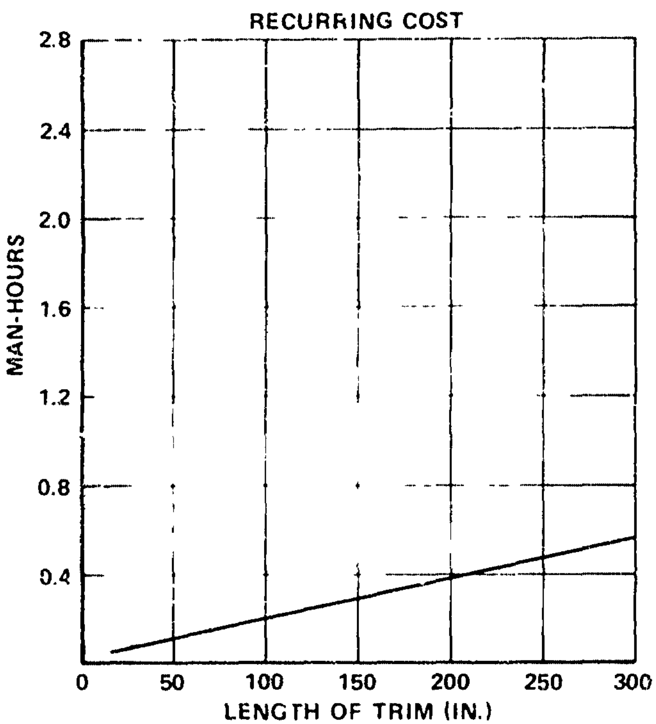
DICE—10

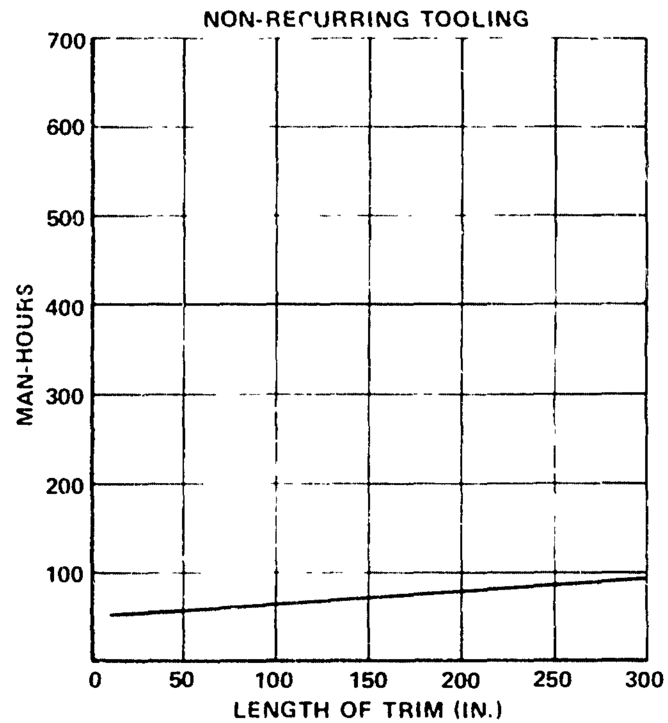
TITANIUM STACK MILL PRIOR TO FORMING



DICE-11

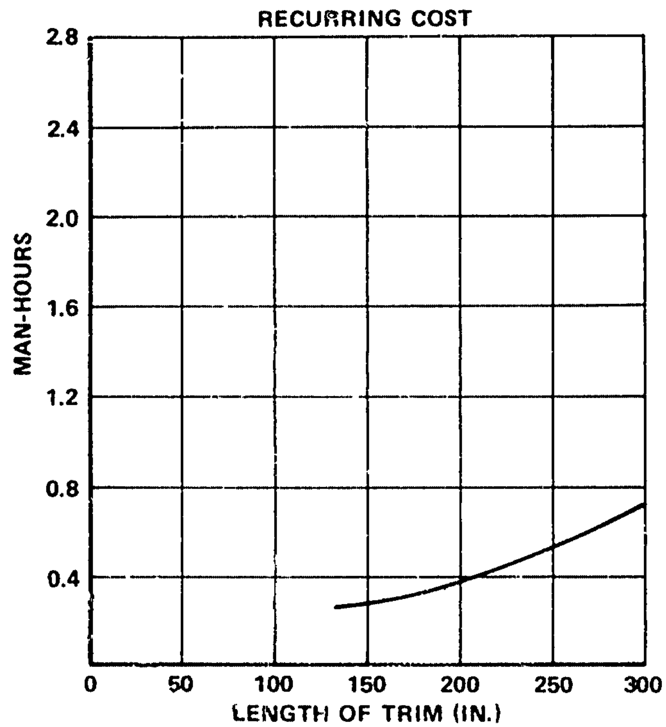
TITANIUM LINEAL PARTS
TRIM AFTER FORMING

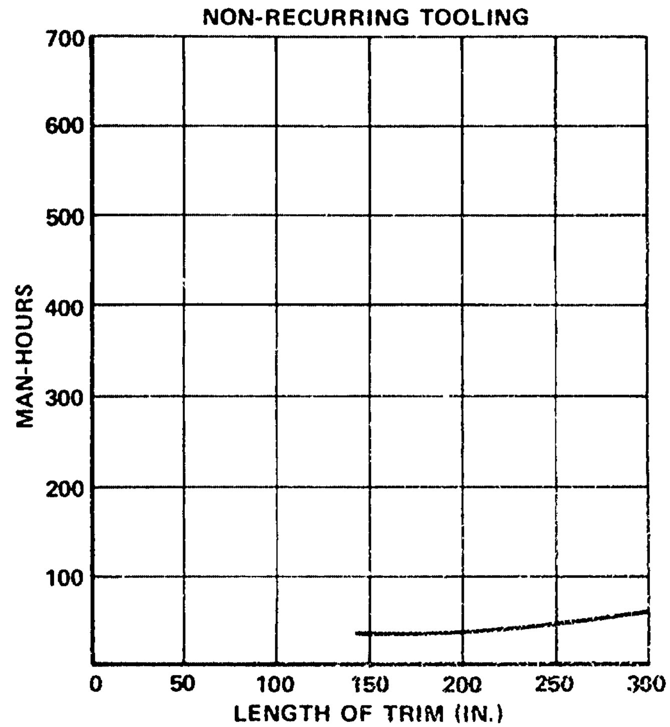




DICE-12

TITANIUM PANELS
TRIM AFTER FORMING





DICE-13

FORMATS FOR

COMPARISON OF MANUFACTURING TECHNOLOGIES

FOR

SHEET-METAL AEROSPACE DISCRETE PARTS

FORMATS FOR COMPARISON OF MANUFACTURING TECHNOLOGIES FOR SHEET-METAL AEROSPACE DISCRETE PARTS

NOTES RELATING TO SHEET-METAL FORMATS

(1) See ground rules for considerations and limitations.

(2) Step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:

- At room temperature forming $\geq$5T
- At elevated temperature forming $\geq$2T.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:

- Elevated temperatures
- Operation in corrosive environments
- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to making a selection of a material or design concept based on the cost of manufacturing.

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as heat treatment, cut-outs, and joggles.

(2) Designer-Influenced Cost Elements (DICE): Includes joggles, cut-outs, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

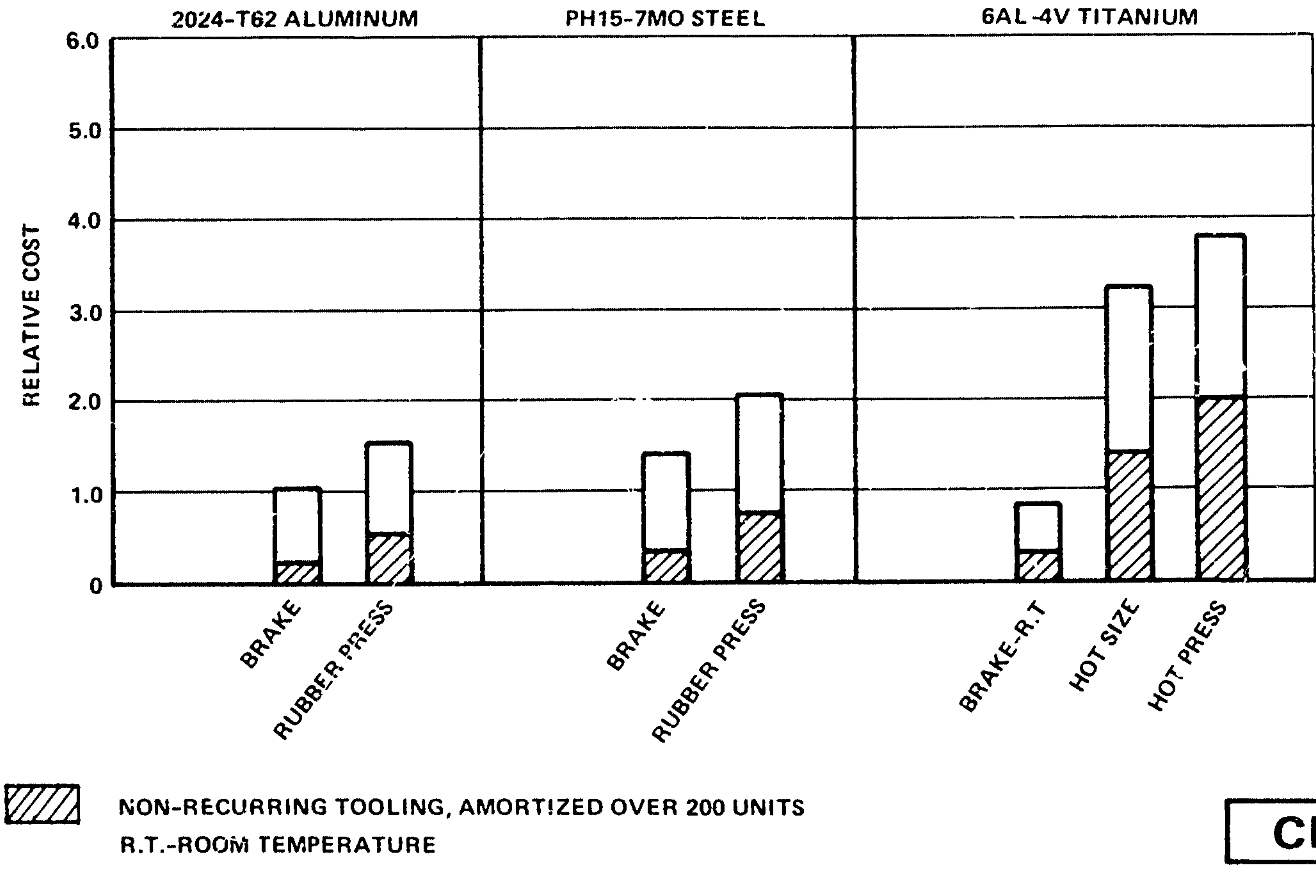
TABLE 8 . FORMATS FOR SHEET-METAL COMPARING MANUFACTURING PROCESSES

Format Number	Format Title
CDE-P-I	Effect of Forming Process and Material on Part Forming Cost: Straight Lineal Shapes
CDE-P-II	Effect of Forming Process and Material on Part Forming Cost: Curved Lineal Shapes
CDE-P-III	Effect of Forming Process and Material on Part Forming Cost: Single Curvature Skin

EFFECT OF FORMING PROCESS AND MATERIAL ON PART FORMING COST

STRAIGHT LINEAL SHAPES

RECURRING PLUS NON-RECURRING COSTS

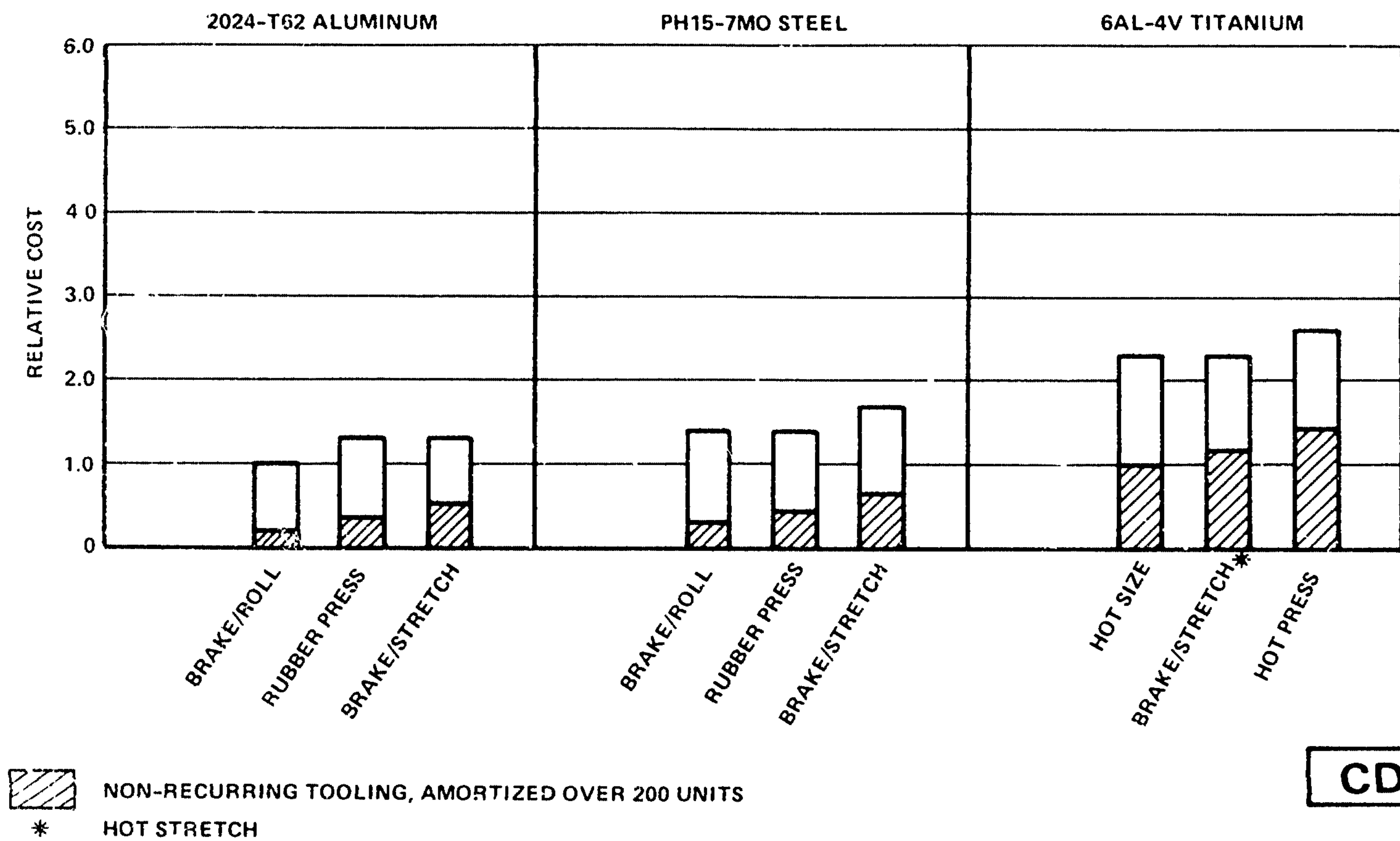


CDE—P-I

EFFECT OF FORMING PROCESS AND MATERIAL ON PART FORMING COST

CURVED LINEAL SHAPES

RECURRING PLUS NON-RECURRING COSTS



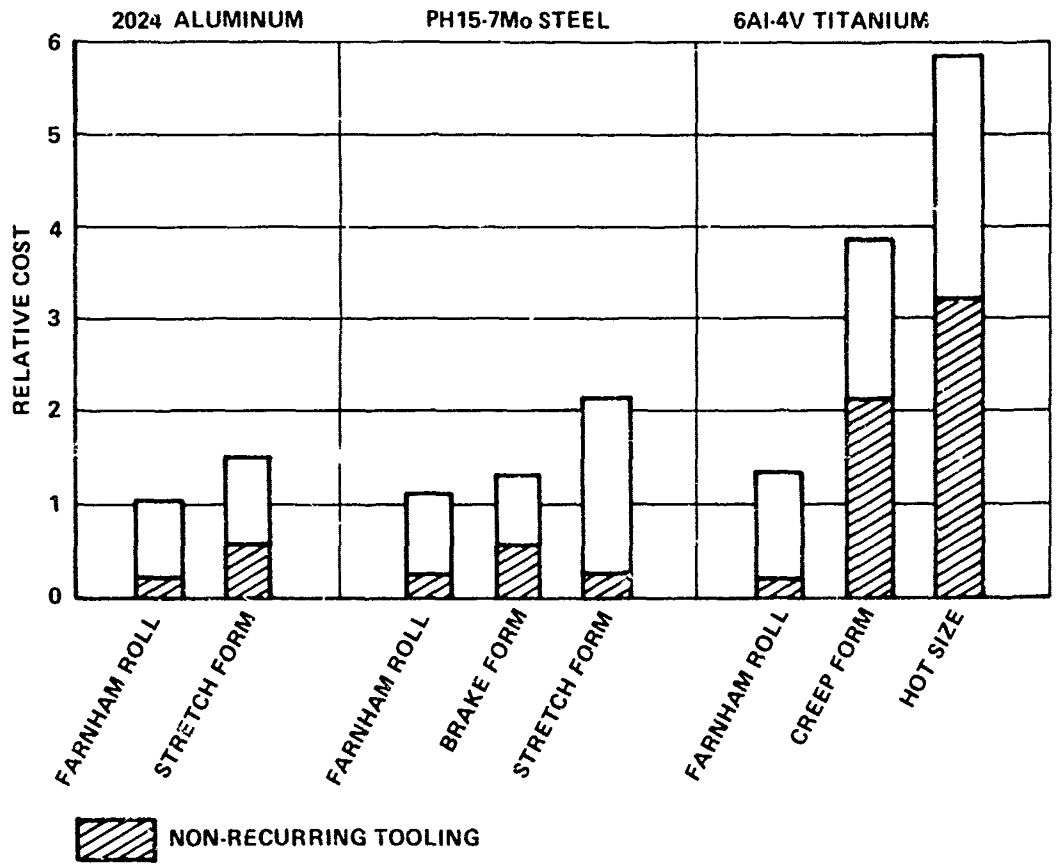
CDE—P-II

SEE GROUND RULES FOR LIMITATIONS AND CONDITIONS

EFFECT OF FORMING PROCESS AND MATERIAL ON PART FORMING COST

SINGLE CURVATURE SKIN

RECURRING PLUS NON-RECURRING COSTS, INCLUDING TRIM



R.T. ~ ROOM TEMPERATURE

FORMATS FOR

COMPARISON OF STRUCTURAL SECTIONS

SHEET-METAL AEROSPACE DISCRETE PARTS

FORMATS FOR COMPARISON OF STRUCTURAL SECTIONS
SHEET-METAL AEROSPACE DISCRETE PARTS

NOTES RELATING TO SHEET-METAL FORMATS

(1) See ground rules for considerations and limitations.

(2) Step occurring in recurring cost man-hours for lineal shapes, at length of 6 feet, due to requirement of two persons for certain manufacturing operations.

(3) Bend radius limitations for titanium:
- At room temperature forming $\geq$5T
- At elevated temperature forming $\geq$2T.

(4) Materials selection: The user of the MC/DG is cautioned with respect to the range of factors that can also play an important role, besides manufacturing cost, in the selection of an airframe material. The airframe design requirements may include:
- Elevated temperatures
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- Higher acquisition costs might be acceptable due to lower operations and maintenance costs.

All factors must be carefully considered by the designer prior to making a selection of a material or design concept based on the cost of manufacturing.

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as heat treatment, cut-outs, and joggles.

(2) Designer-Influenced Cost Elements (DICE): Includes joggles, cut-outs, lightening holes, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

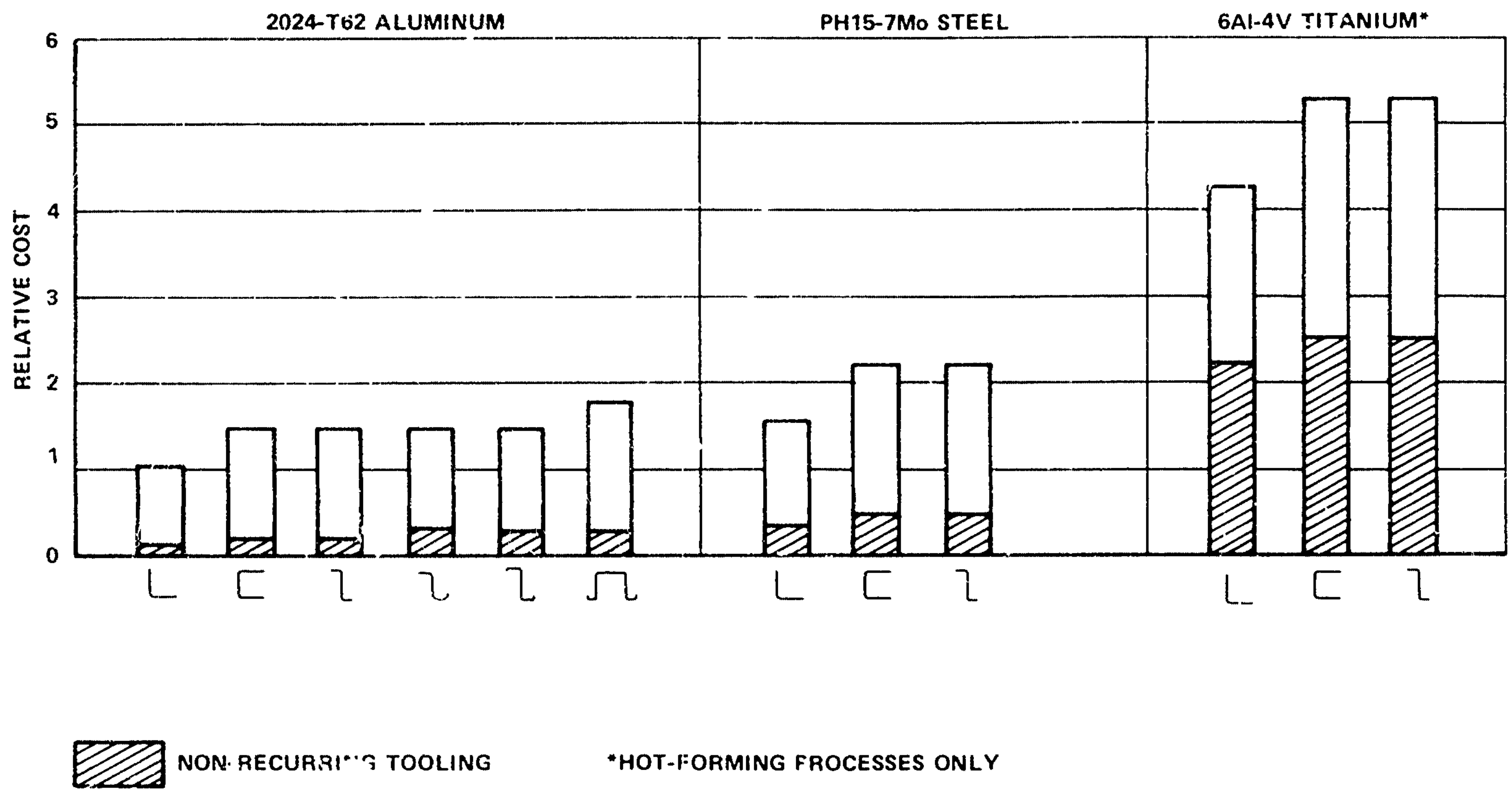
(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 9 . FORMATS FOR SHEET-METAL COMPARING STRUCTURAL SECTIONS

Format Number	Format Title
CDE-M-I	Effect of Cross-Section and Material on Part Forming Cost: Straight Lineal Shapes
CDE-M-II	Effect of Cross-Section and Material on Part Forming Cost: Curved Lineal Shapes
CED-M-1	Straight Aluminum Lineal Shapes: Brake Form
CED-M-2	Straight Aluminum Lineal Shapes: Brake Form, Heat Treated to T62
CED-M-3	Straight and Contoured Aluminum Lineal Shapes: Rubber Press
CED-M-4	Contoured Aluminum Lineal Shapes: Brake and Roll
CED-M-5	Contoured Aluminum Lineal Shapes: Brake and Roll, Heat Treated to T62
CED-M-6	Contoured Aluminum Lineal Shapes: Brake and Stretch, Heat Treated to T62
CED-M-7	Contoured Aluminum Lineal Shapes: Brake and Stretch, Heat Treated to T62
CED-M-8	Straight Steel Lineal Shapes: Brake Form
CED-M-9	Straight and Contoured Steel Lineal Shapes: Rubber Press
CED-M-10	Contoured Steel Lineal Shapes: Brake and Stretch
CED-M-11	Straight Titanium Lineal Shapes: Brake Form
CED-M-12	Straight Titanium Lineal Shapes: Preform and Hot Size
CED-M-13	Straight and Contoured Titanium Lineal Shapes: Hot Press
CED-M-14	Contoured Titanium Lineal Shapes: Room Temperature Brake and Hot Stretch
CED-M-15	Contoured Titanium Lineal Shapes: Preform and Hot Size

EFFECT OF CROSS-SECTION AND MATERIAL ON PART FORMING COST

STRAIGHT LINEAL SHAPES
RELATIVE RECURRING PLUS NON-RECURRING COST

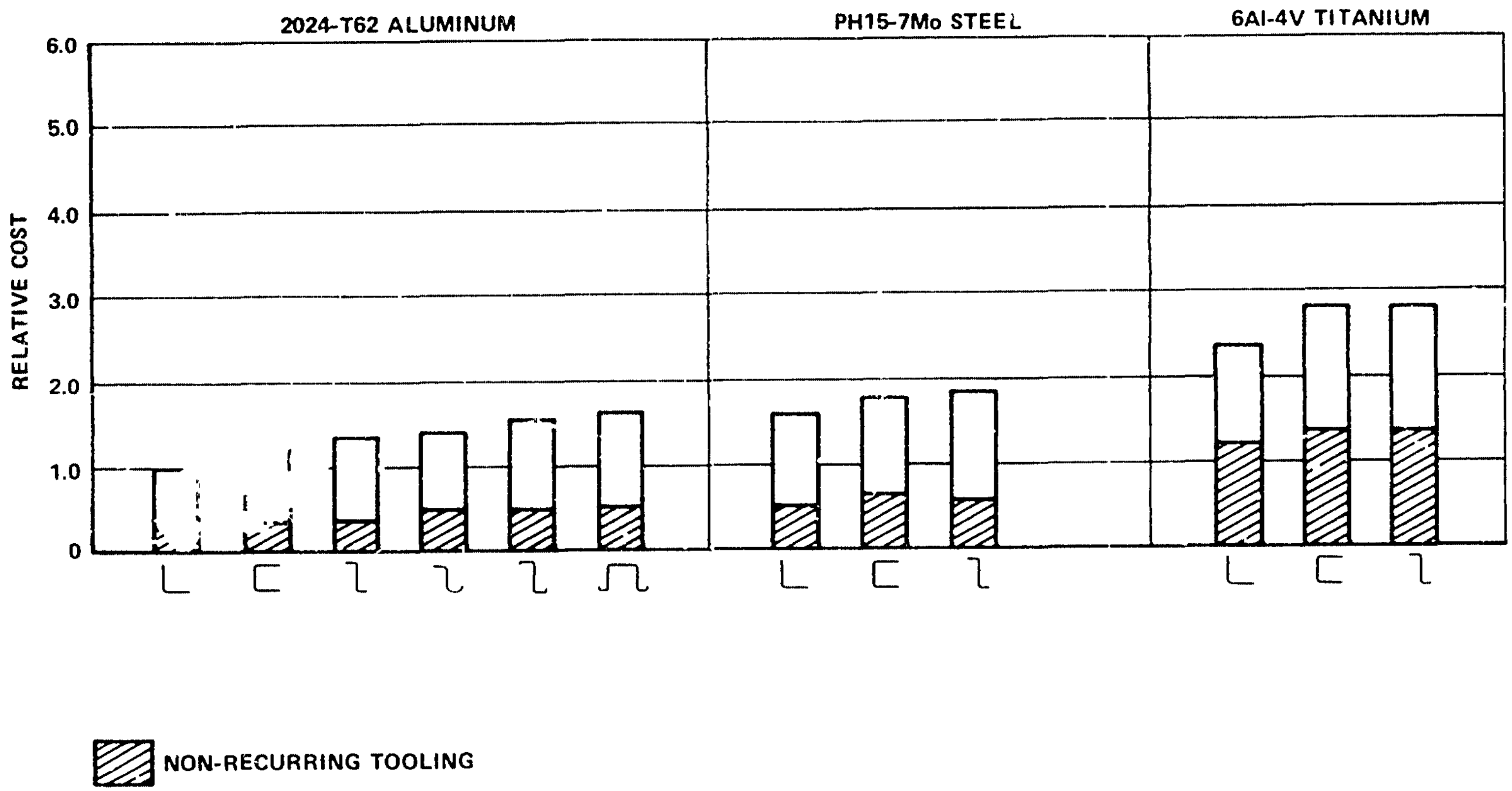


CDE—M-I

EFFECT OF CROSS-SECTION AND MATERIAL ON PART FORMING COST

CURVED LINEAL SHAPES

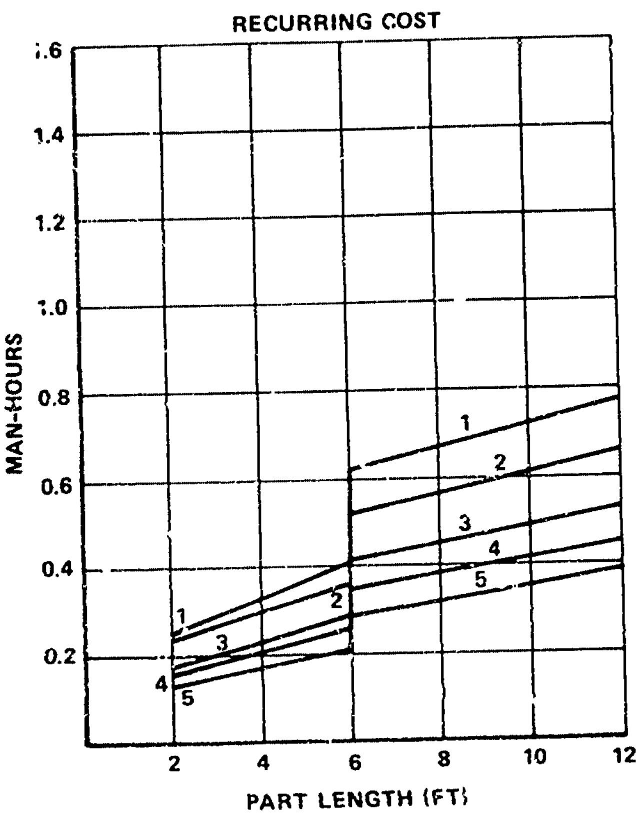
RELATIVE RECURRING PLUS NON-RECURRING COST

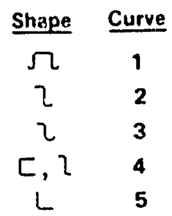


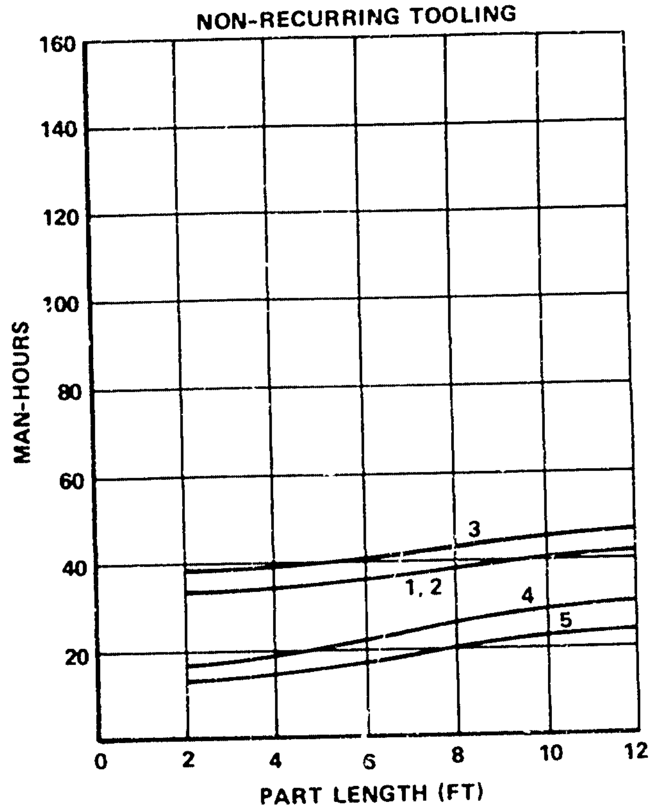
CDE—M-II

STRAIGHT ALUMINUM LINEAL SHAPES

BRAKE FORM





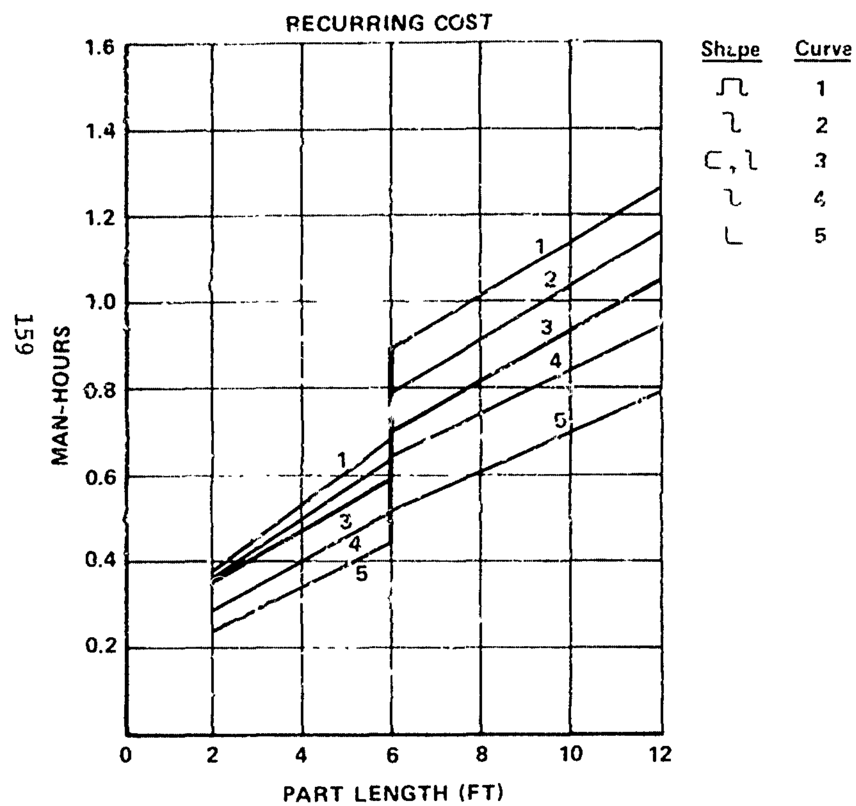


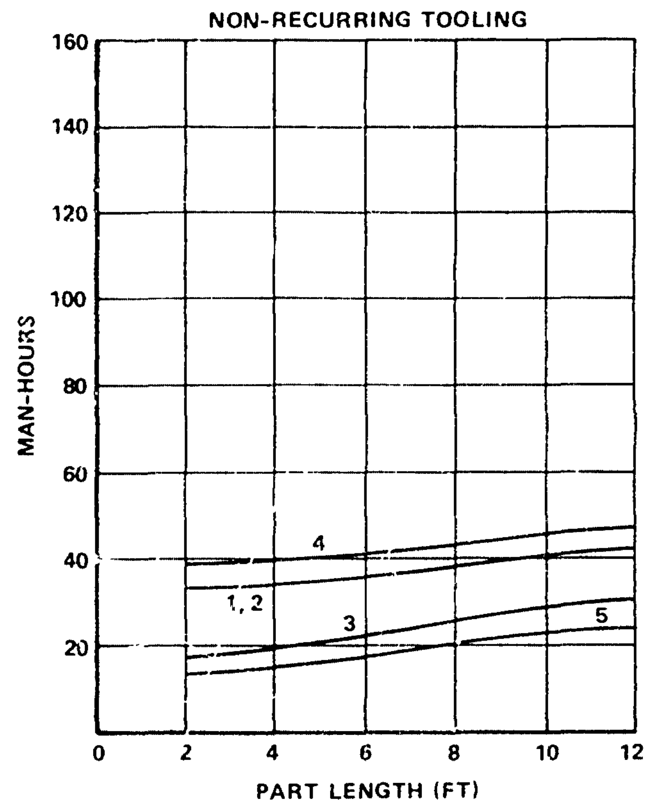
CED—M-1

STRAIGHT ALUMINUM LINEAL SHAPES

BRAKE FORM

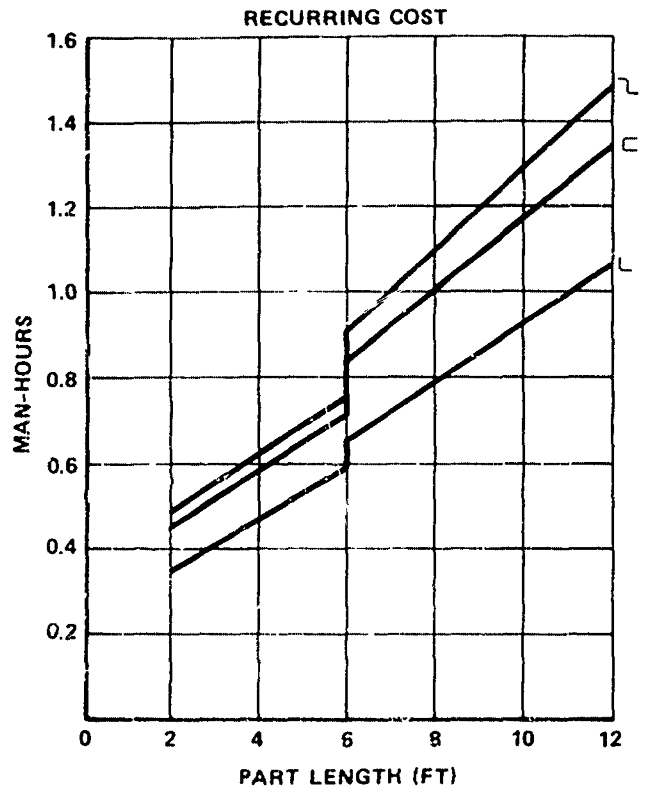
HEAT TREATED TO T62

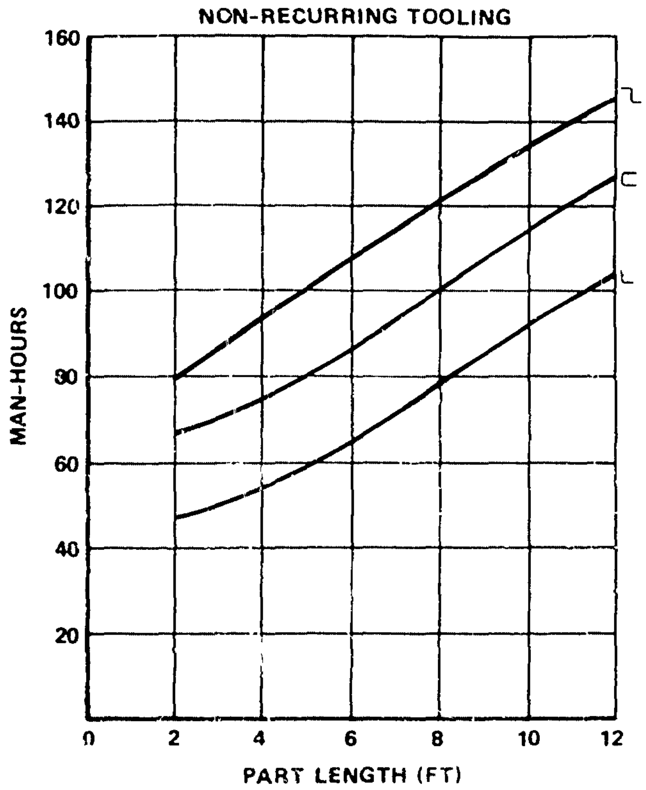




CED—M-2

STRAIGHT AND CONTOURED, ALUMINUM LINEAL SHAPES
RUBBER PRESS

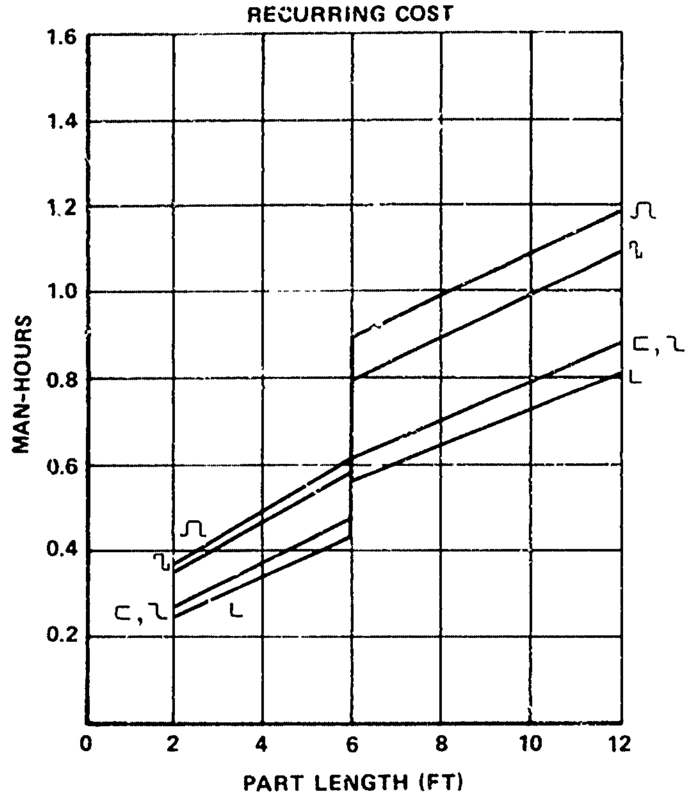


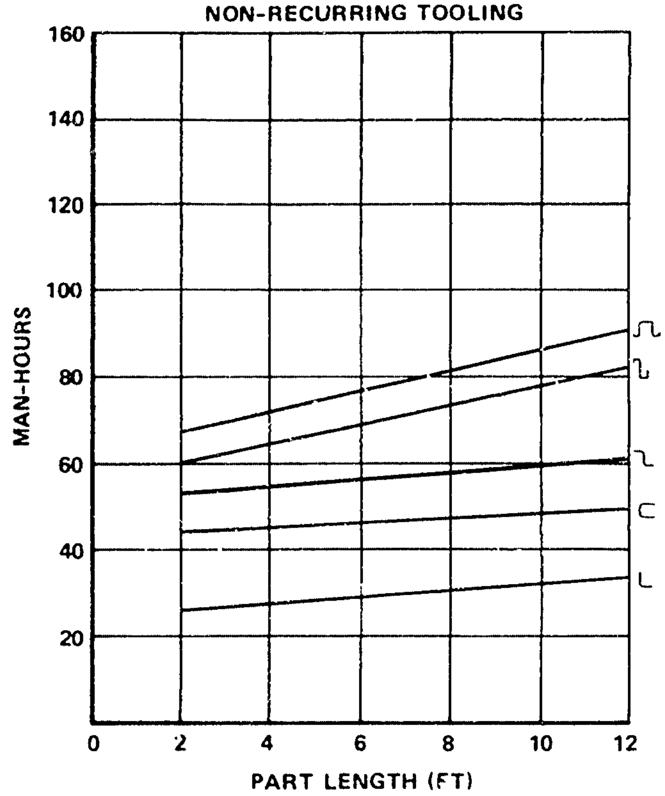


CED—M-3

CONTOURED ALUMINUM LINEAL SHAPES

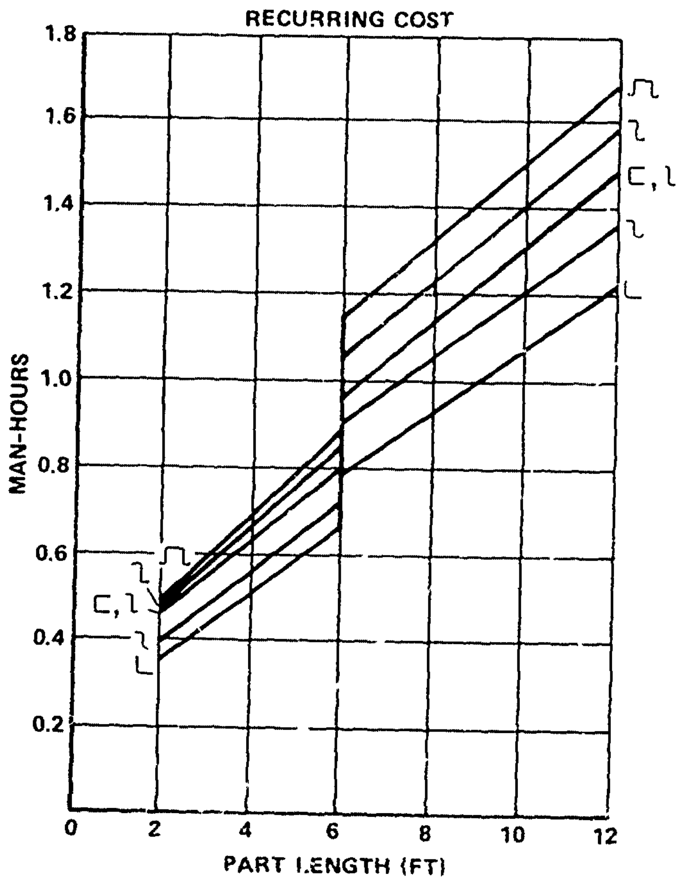
BRAKE AND ROLL

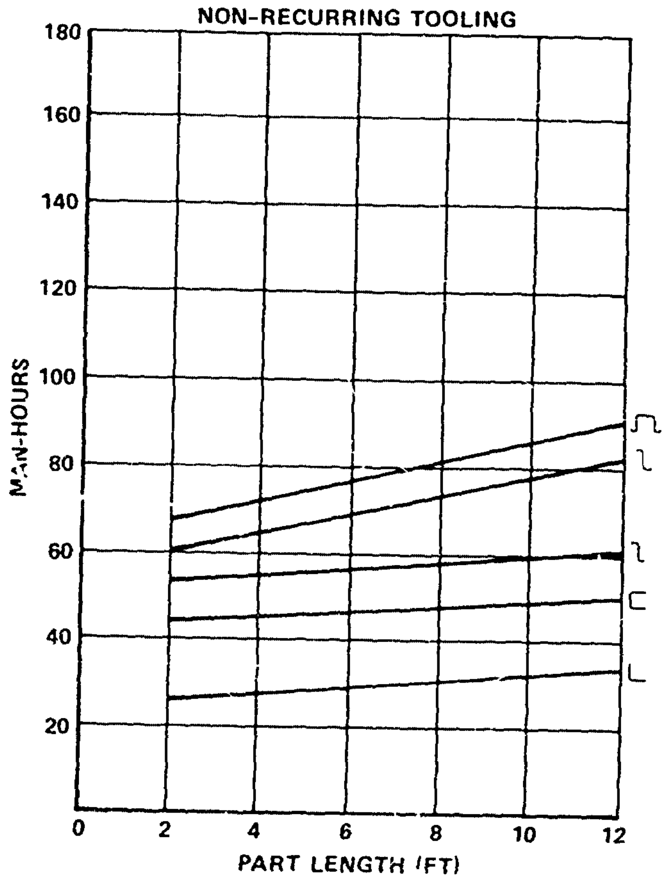




CED—M-4

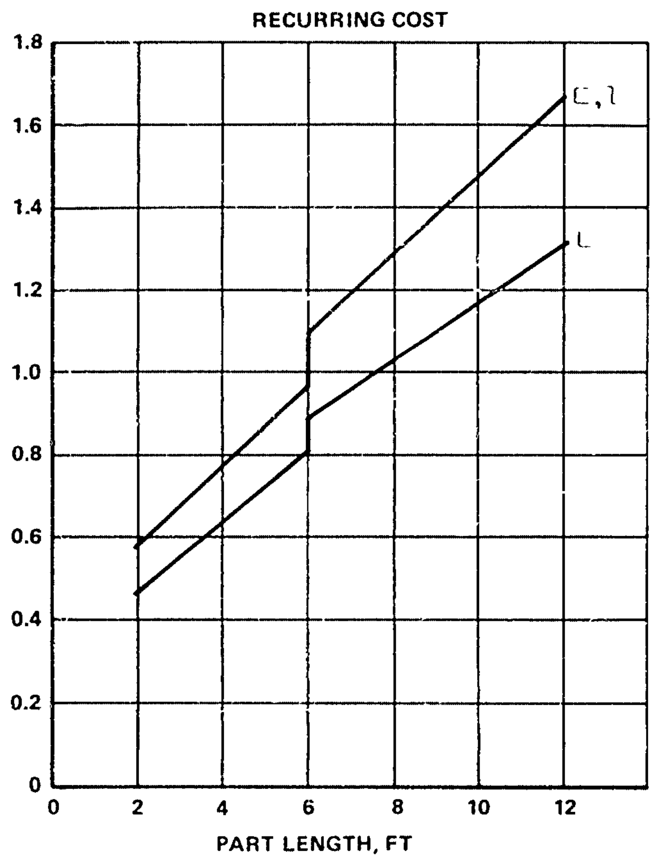
CONTOURED ALUMINUM LINEAL SHAPES
BRAKE AND ROLL
HEAT TREATED TO T62

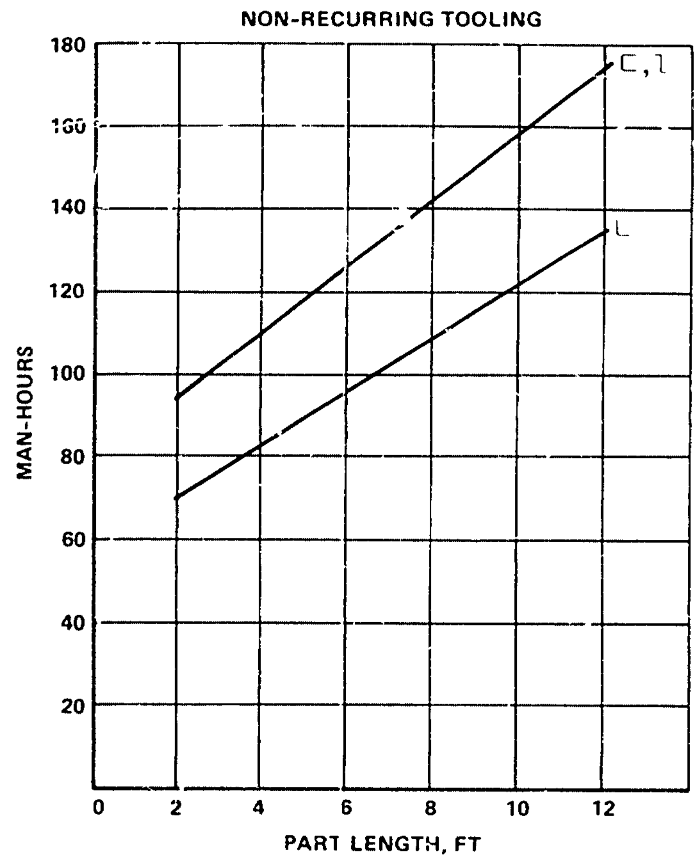




CED—M-5

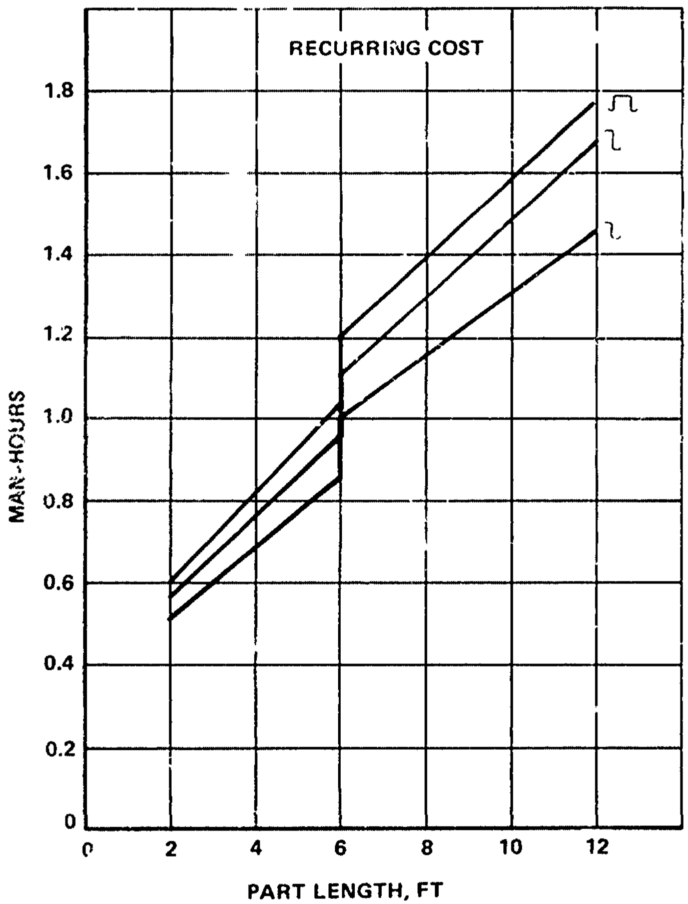
CONTOURED ALUMINUM LINEAL SHAPES
BRAKE AND STRETCH
HEAT TREATED TO T62

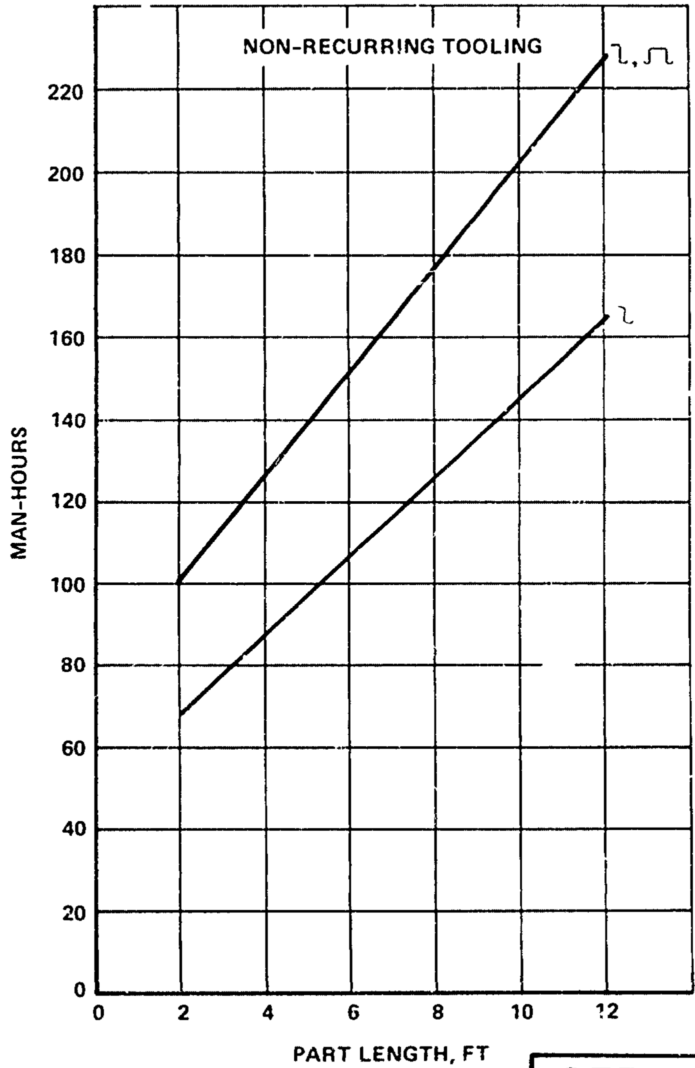




CED—M-6

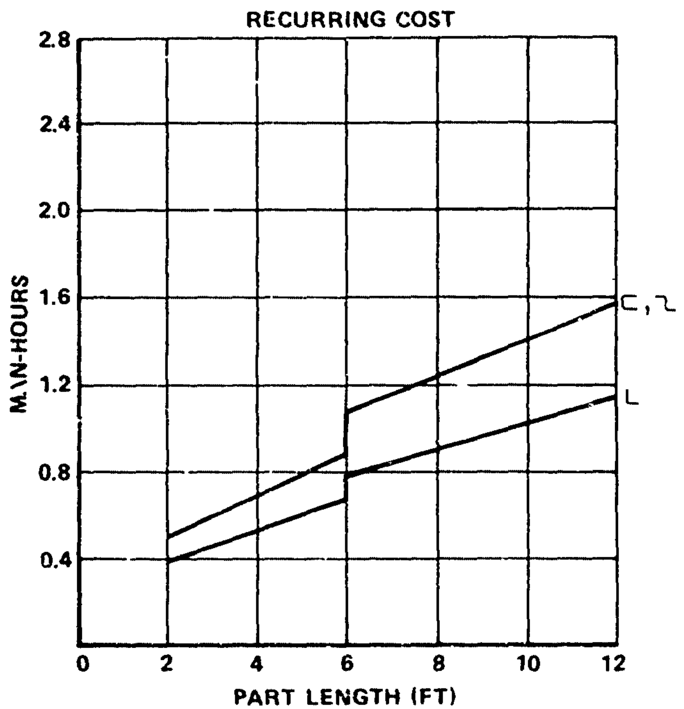
CONTOURED ALUMINUM LINEAL SHAPES
HEAT TREATED TO T62
BRAKE AND STRETCH

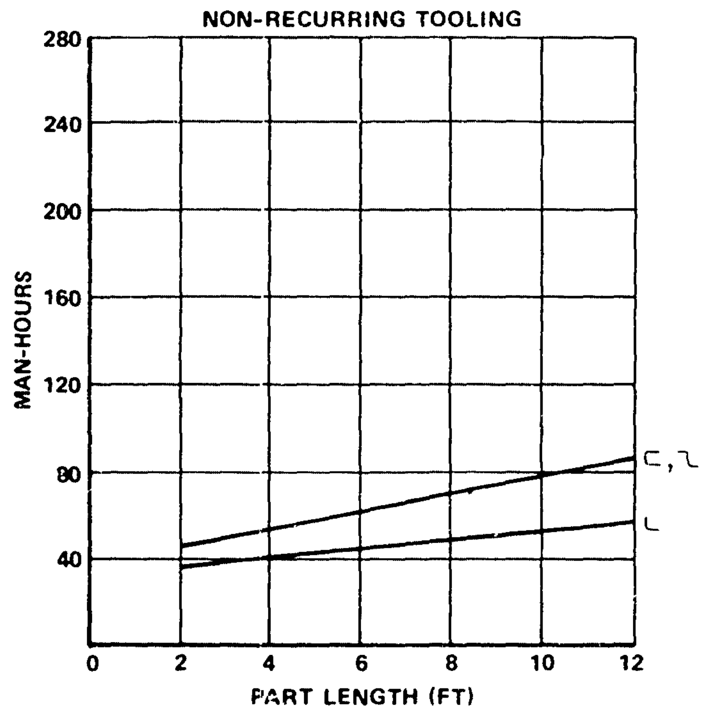




CED—M-7

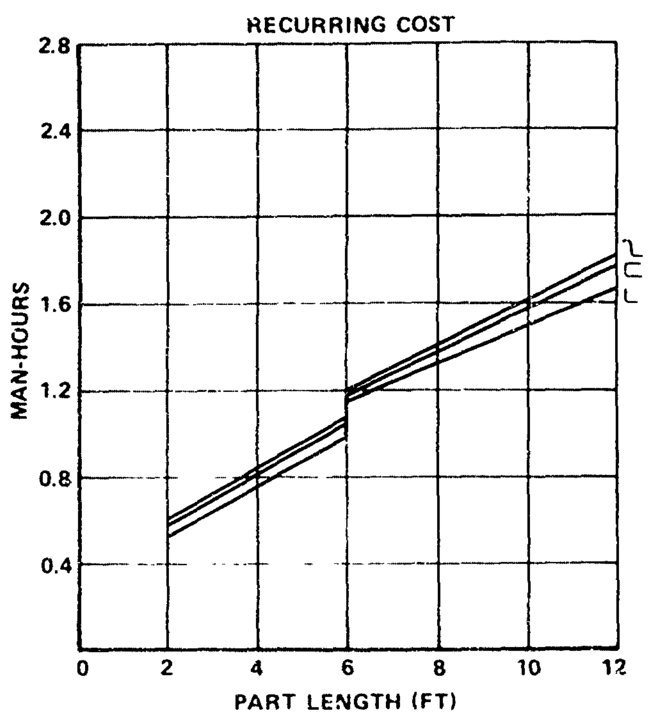
STRAIGHT STEEL LINEAL SHAPES
BRAKE FORM

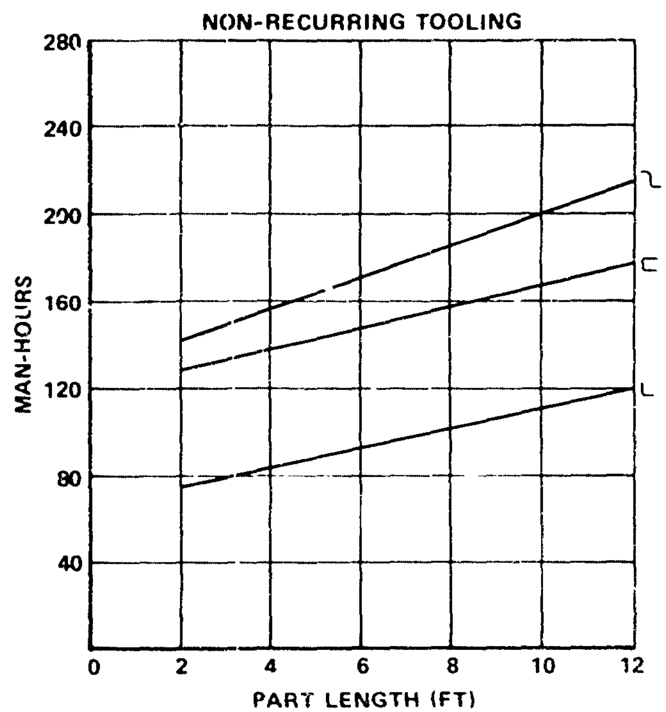




CED—M-8

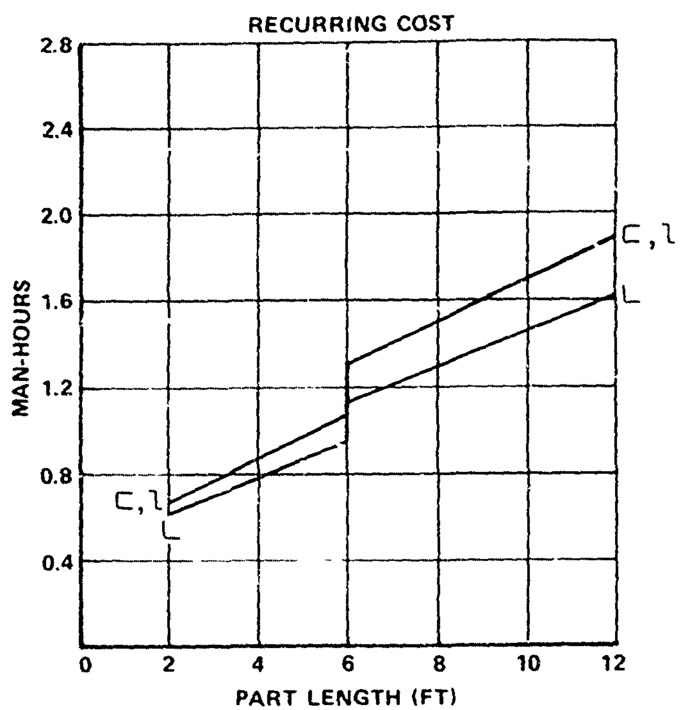
STRAIGHT AND CONTOURED STEEL LINEAL SHAPES
RUBBER PRESS

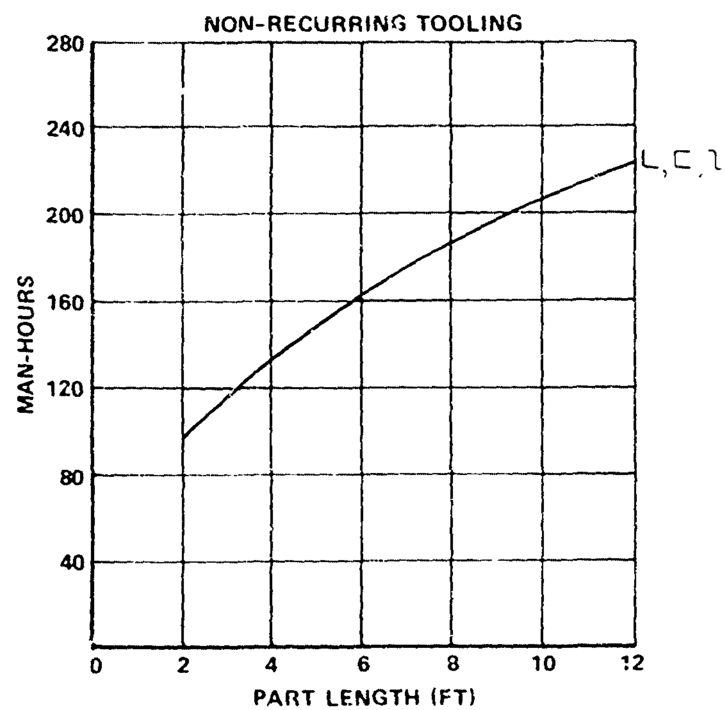




CED—M-9

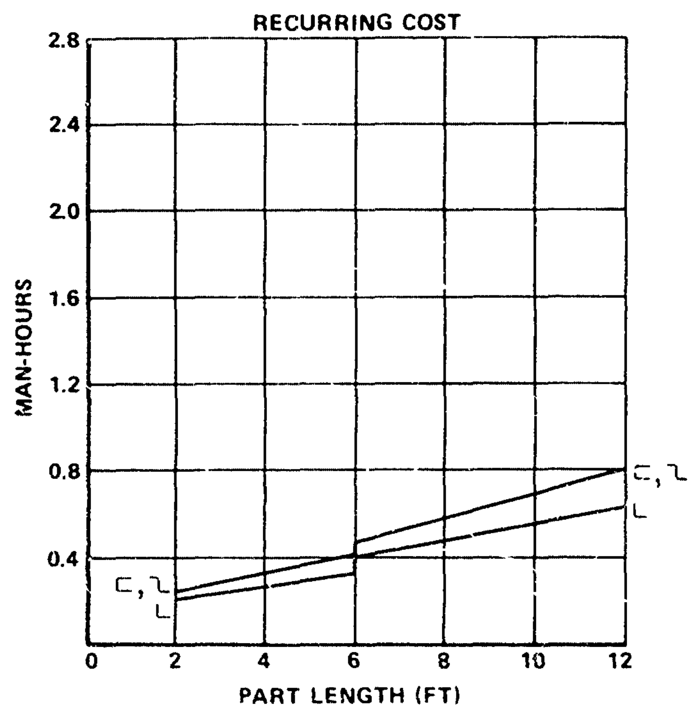
CONTOURED STEEL LINEAL SHAPES
BRAKE AND STRETCH

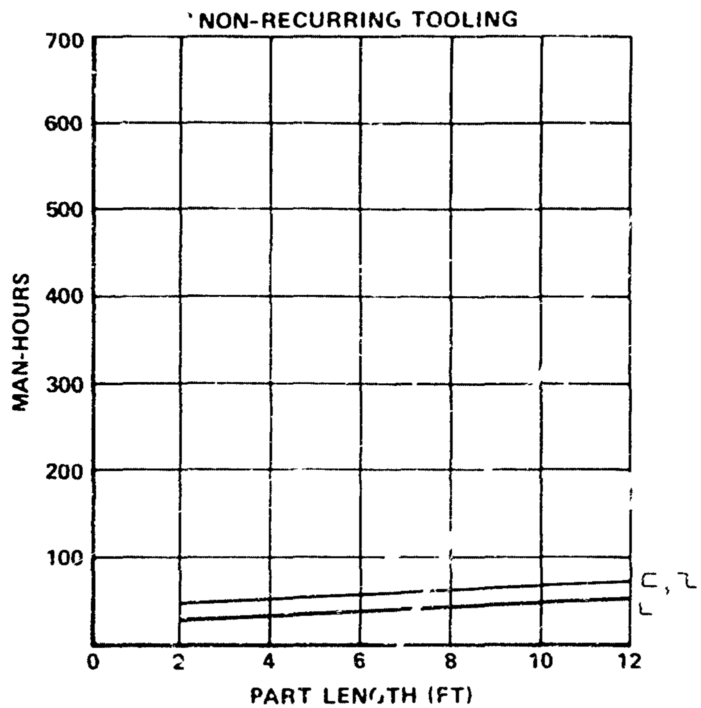




CED—M-10

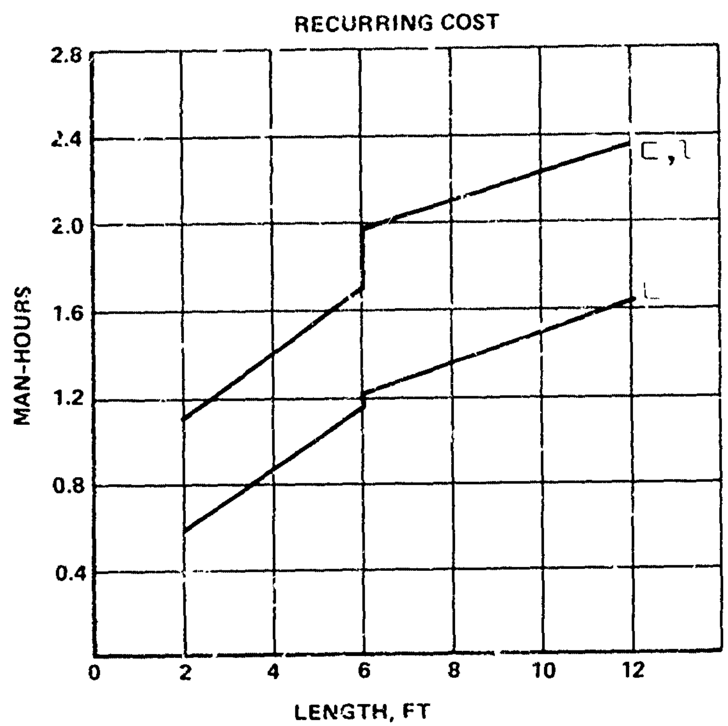
STRAIGHT TITANIUM LINEAL SHAPES
BRAKE FORM

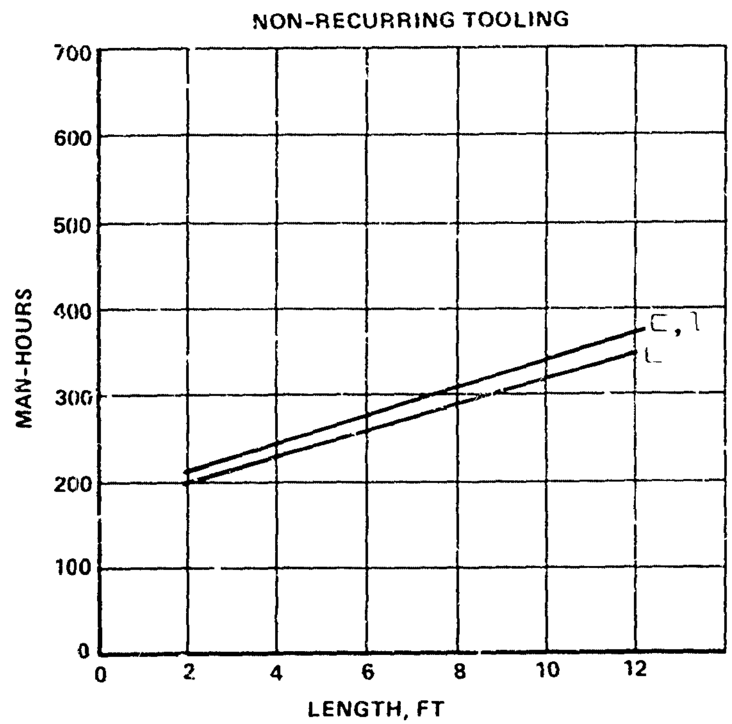




CED—M-11

STRAIGHT TITANIUM LINEAL SHAPES
PREFORM AND HOT SIZE

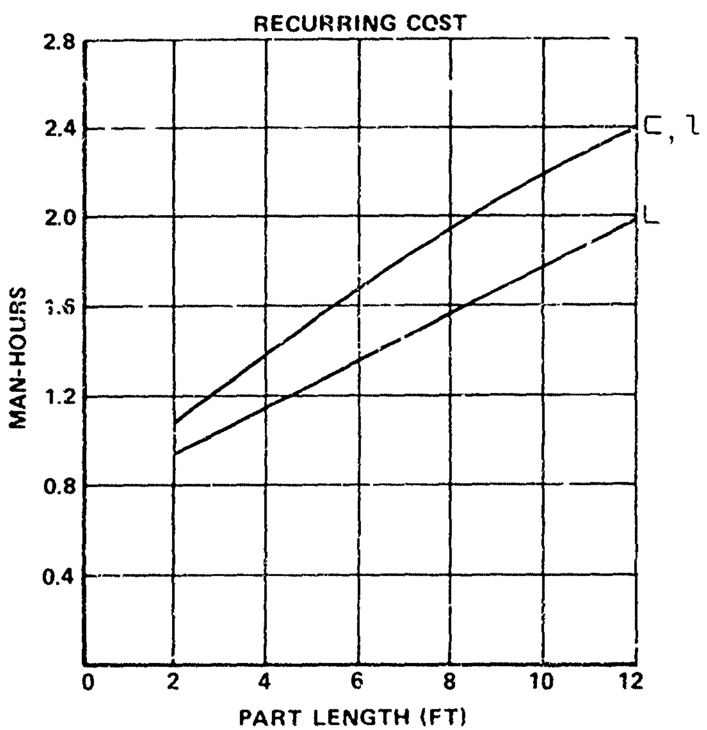


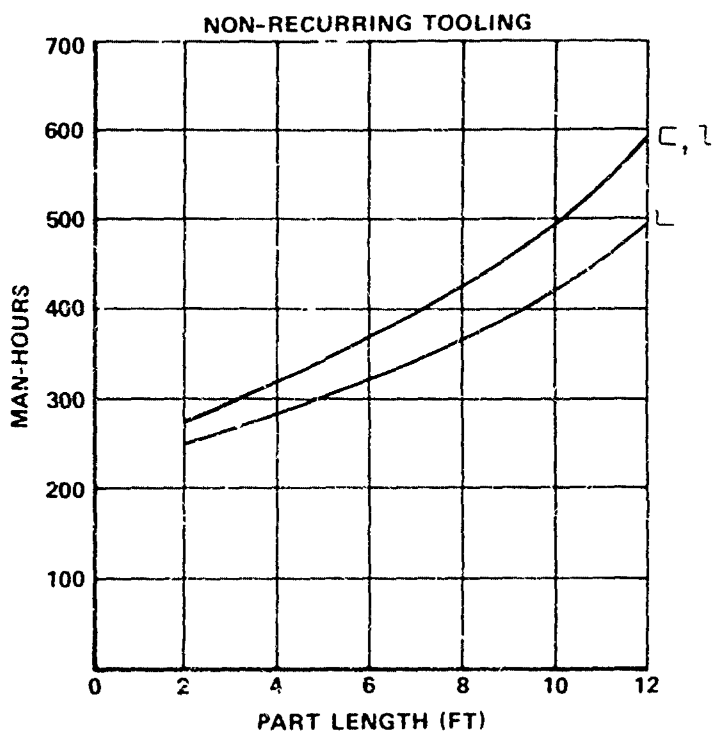


CED—M-12

STRAIGHT AND CONTOURED TITANIUM LINEAL SHAPES

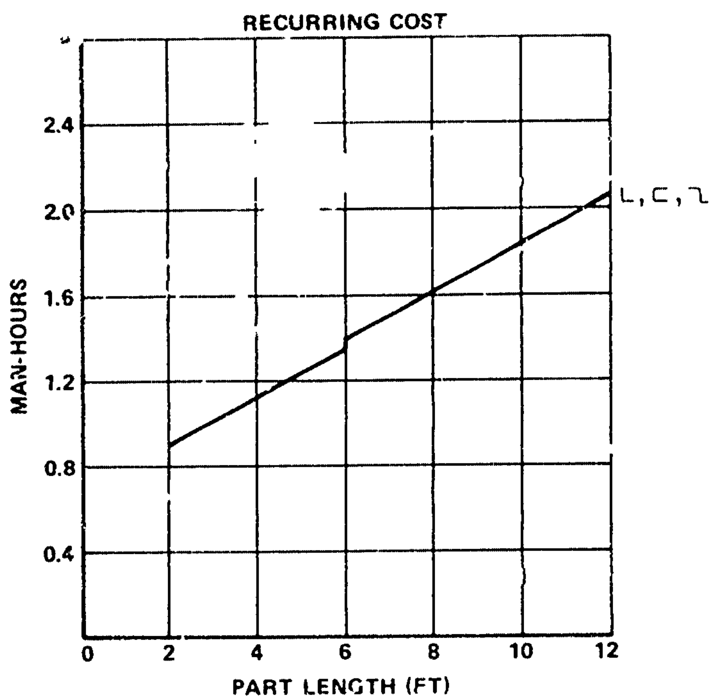
HOT PRESS

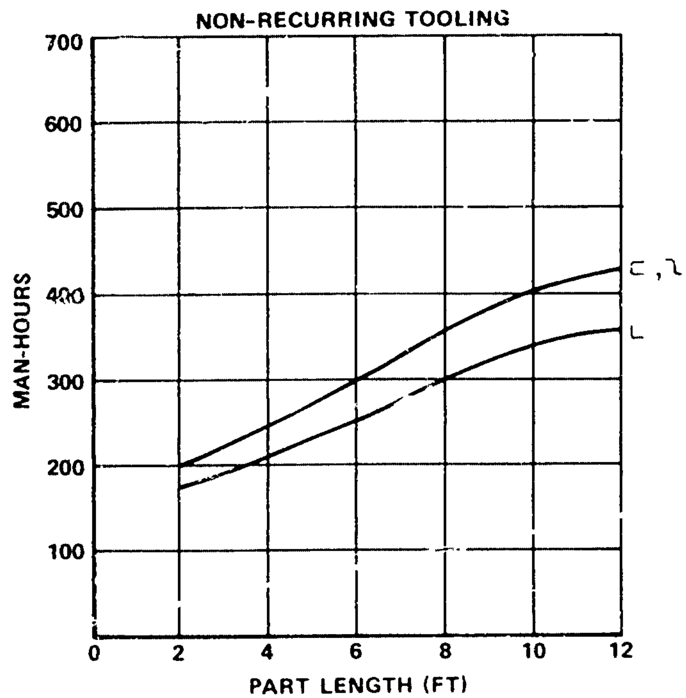




CED—M-13

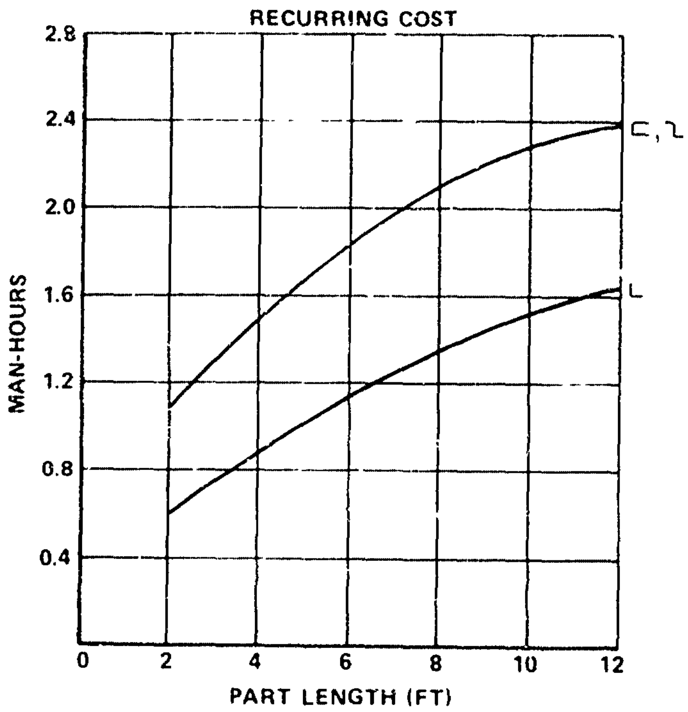
CONTOURED TITANIUM LINEAL SHAPES
ROOM TEMPERATURE BRAKE AND HOT STRETCH

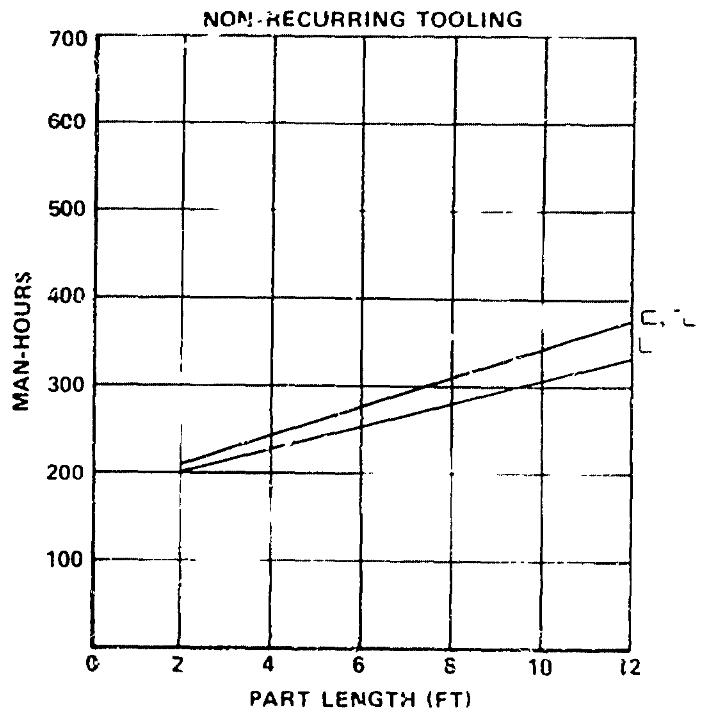




CED—M-14

CONTOURED TITANIUM LINEAL SHAPES
PREFORM AND HOT SIZE





CED—M-15

SECTION VIII

MECHANICALLY FASTENED ASSEMBLY DEMONSTRATION SECTION

Mechanical fastening assembly in airframe manufacture can be responsible for 15 to 30 percent of the total cost. This is pointed out in Reference 2. Contributing factors to this cost are the proliferation of fastener types and the different methods of installation. The number of fasteners in attack-type aircraft, for example, can range from 400,000 to 750,000; and in a transport aircraft, the number can exceed several million. In a typical transport aircraft, the cost of fasteners alone can exceed $2.5 million.

The above approximate percentages indicate the assembly cost for the total airframe structure. However, a study of the weight and cost distribution for major subassemblies of aircraft (Reference 2) indicates that the cost of assembly for the wing of a transport aircraft ranges from 30 to 55 percent, and for a fuselage, from approximately 40 to 48 percent of the total cost. However, for other components, such as leading and trailing edges and empennage, the cost is considerably lower.

A vast amount of information on assembly and associated cost drivers costs is available to designers. Many thrusts, such as integrally stiffened panels and advanced composite fabrication, have indeed been stimulated by the urgency to reduce assembly costs. However, due to the complex nature of assembly and the cost drivers responsibile for this high cost, the designer must continually consider cost reduction of assembly in all phases of his work. Tools must be provided to him so that he can conduct credible structural performance/manufacturing cost trade studies and, at the same time, achieve the meaningful dialogues necessary with all disciplines involved in the aircraft system development, in particular, manufacturing.

The results of Air Force cost reduction studies, References 1 and 2, provided the perspective required by industry and the Air Force of mechanical assembly cost and cost drivers. and these important results emphasized the urgent necessity of developing a Demonstration Section on Mechanically Fastened Assemblies for immediate utilization by the designer.

To develop the required recurring and non-recurring costs (man-hours) for the Mechanically Fastened Assembly Demonstration Section, a series of assemblies were analyzed. However, it was not possible, at this time, to develop a complete section on mechanically fastened assemblies covering all the alternative materials, joint designs, fastener types, and facilities. A series of panels were selected and studied in a consistent manner based on MC/DG coalition-developed ground rules. These assemblies are listed in Table 10 and are:

- Avionics panel
- Fuselage door
- Fuselage panel with cut-out.

The cost drivers in mechanically fastened assemblies are:

- Accessibility for fastener installation
- Jigging requirements
- Sequencing requirements
- Materials to be joined
- Sealing
- Quantity
- Stackup of parts
- Number of parts
- Number of fasteners
  - Hand rivets
  - Drivematic rivets
  - Threaded fasteners
- Tolerances.

The cost drivers analyzed in this Demonstration Section are:

- Accessibility
- Materials joined
- Fastener count
- Part count
- Sealing.

TABLE 10. CODE FOR MECHANICALLY FASTENED ASSEMBLIES

Assembly Type	Material	Size Classification	Size, Inches
Avionics Bay Panel	Aluminum-1	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Panel	Aluminum-2	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Door	Aluminum-3	A	24x36
		B	24x72
		C	48x36
		D	48x96
Avionics Bay Panel	Titanium-1	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Panel	Titanium-2	A	24x36
		B	24x72
		C	48x36
		D	48x96
Fuselage Door	Titanium-3	A	24x36
		B	24x72
		C	48x36
		D	48x96

MECHANICALLY FASTENED ASSEMBLIES

DEMONSTRATION SECTION

MECHANICALLY FASTENED ASSEMBLIES DEMONSTRATION SECTION

CONTENTS

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COST DRIVERS ANALYZED	178
ASSEMBLIES ANALYZED	179
FORMAT SELECTION AID	184
EXAMPLE OF UTILIZATION	185
FORMATS	190
Cost-Driver Effects (CDE)	190
Cost-Estimating Data (CED)	201

"MANUFACTURING COST/DESIGN GUIDE (MC/DG)"

COST–DRIVERS IN MECHANICALLY FASTENED ASSEMBLY FABRICATION

COST–DRIVERS ANALYZED IN PHASE II(A)

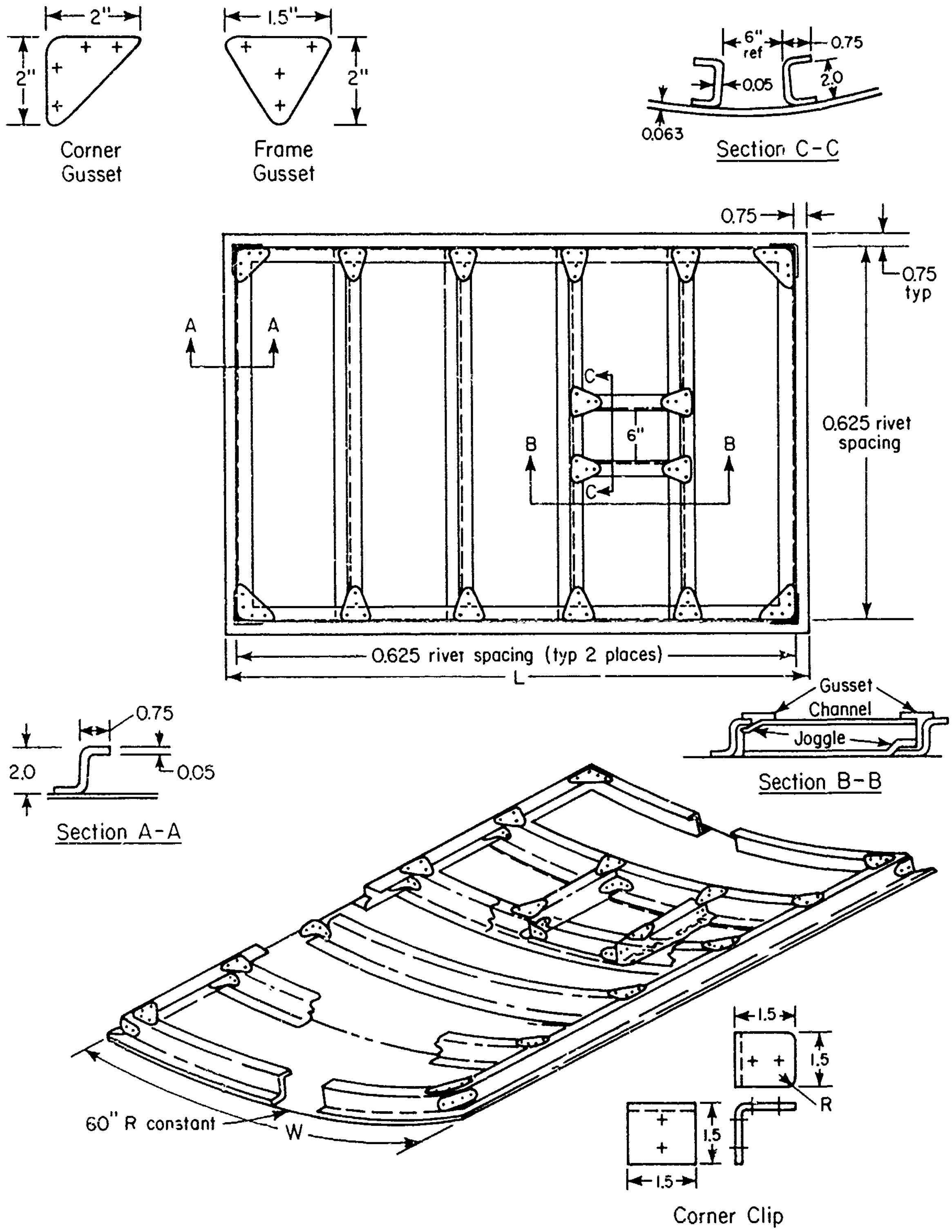
- ACCESSIBILITY
- MATERIALS JOINED
- FASTENER COUNT
- PART COUNT
- SEALING

MECHANICALLY FASTENED ASSEMBLIES

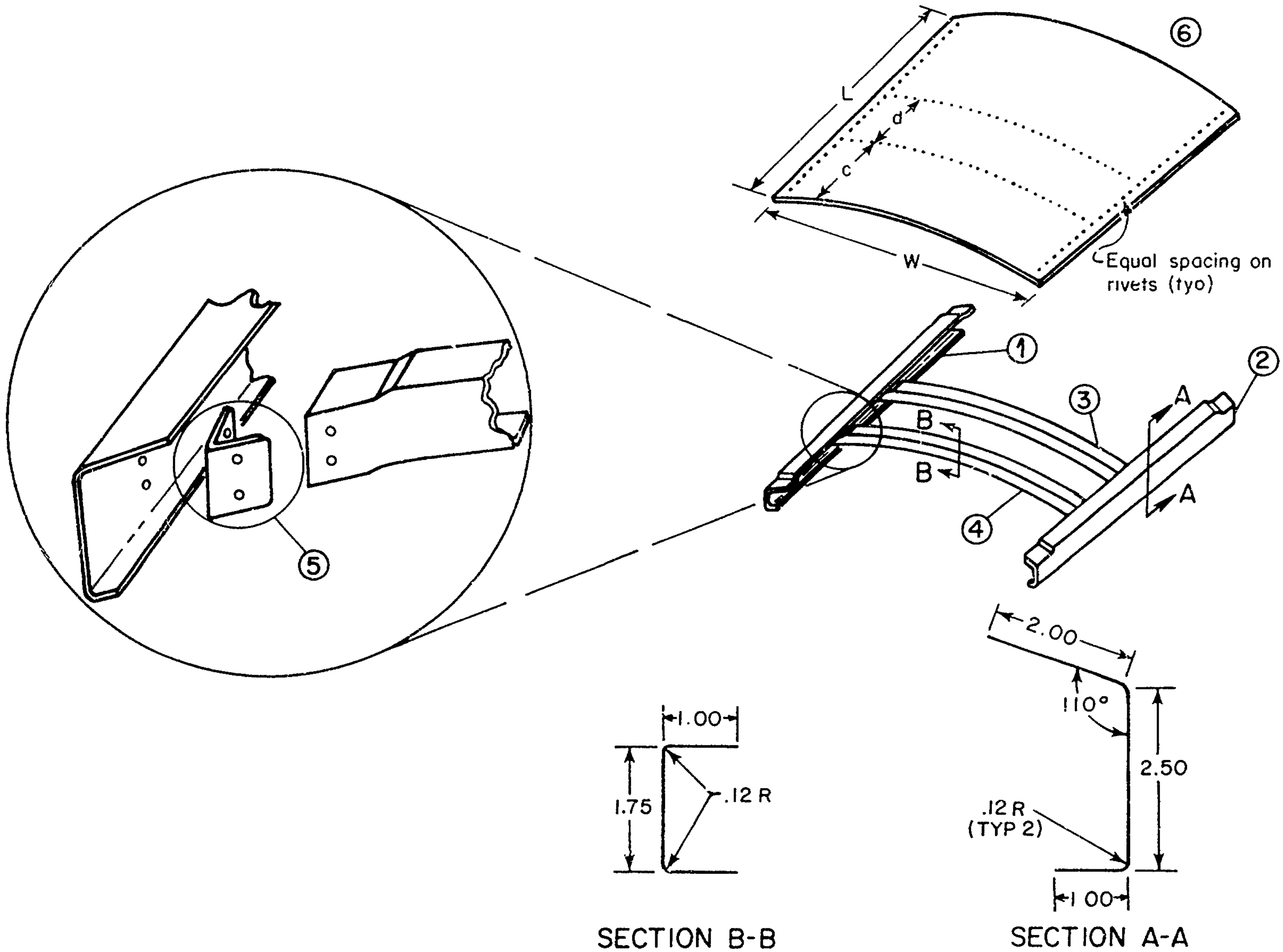
DEMONSTRATION SECTION

ASSEMBLIES ANALYZED

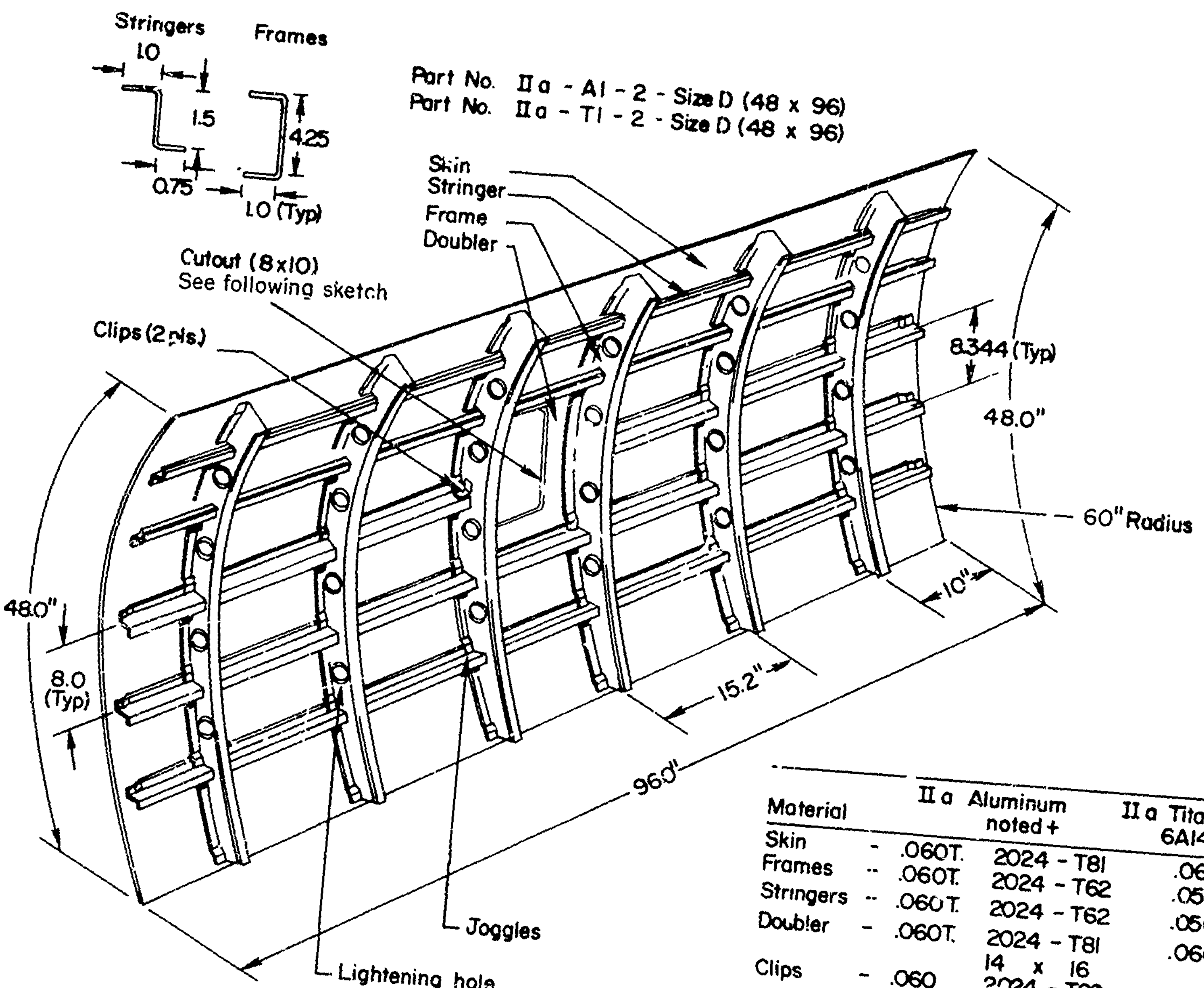
MECHANICALLY FASTENED ASSEMBLIES DEMONSTRATION SECTION
ASSEMBL[illegible]S ANALYZED



FUSELAGE DOOR ASSEMBLY



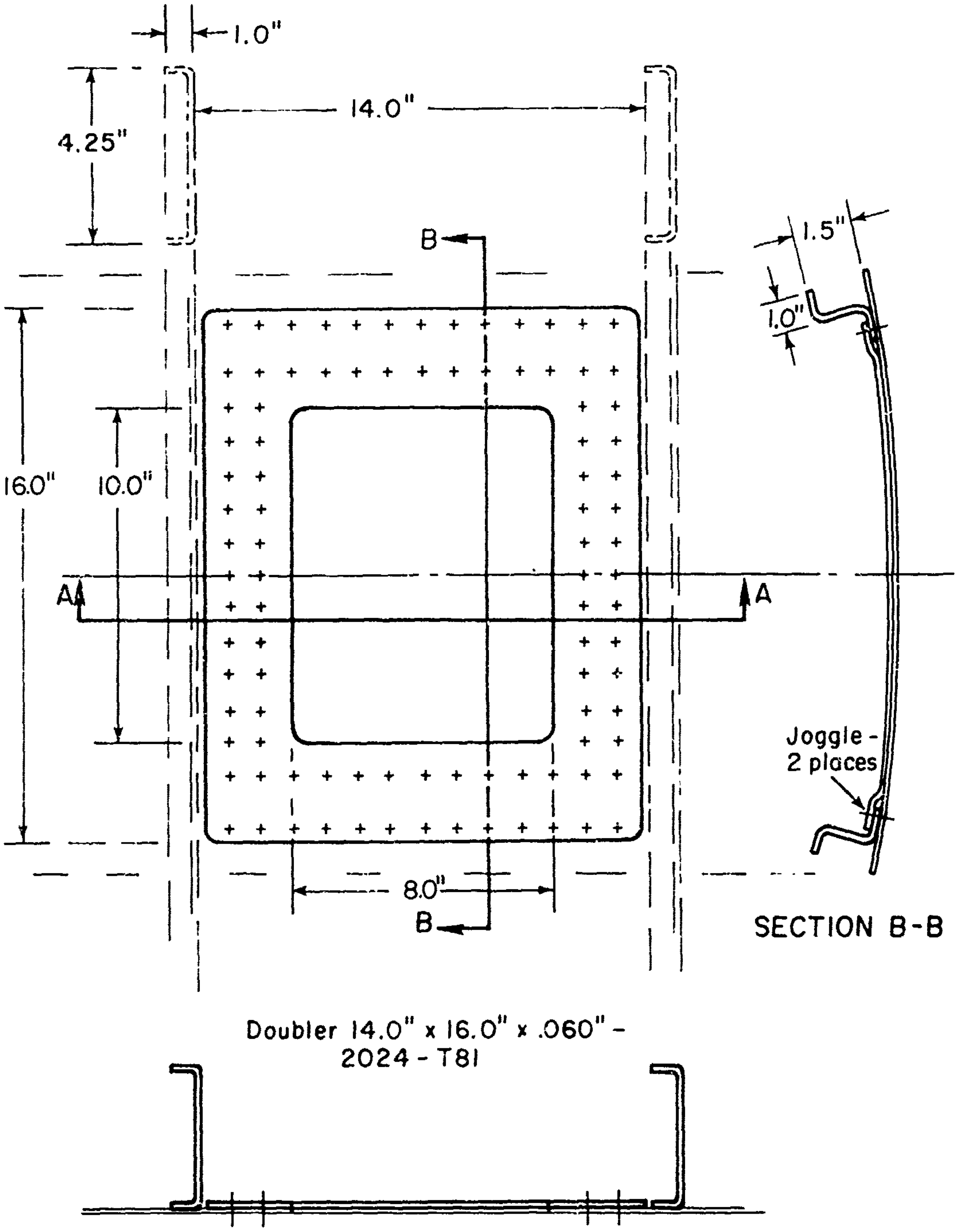
AVIONICS BAY PANEL



Material		II a Aluminum noted +		II a Titanium 6Al4V
Skin	-	.060T.	2024 - T81	.060
Frames	--	.060T.	2024 - T62	.050
Stringers	--	.060T.	2024 - T62	.050
Doubler	-	.060T.	2024 - T81	.060
Clips	-	.060	14 x 16 2024 - T62	

**MECHANICALLY FASTENED ASSEMBLY
FUSELAGE PANEL**

IIa - AL-1 - SIZE A (24" x 36")
SIZE B (24" x72")
SIZE C (48" x 36")
SIZE D (48" x 96")



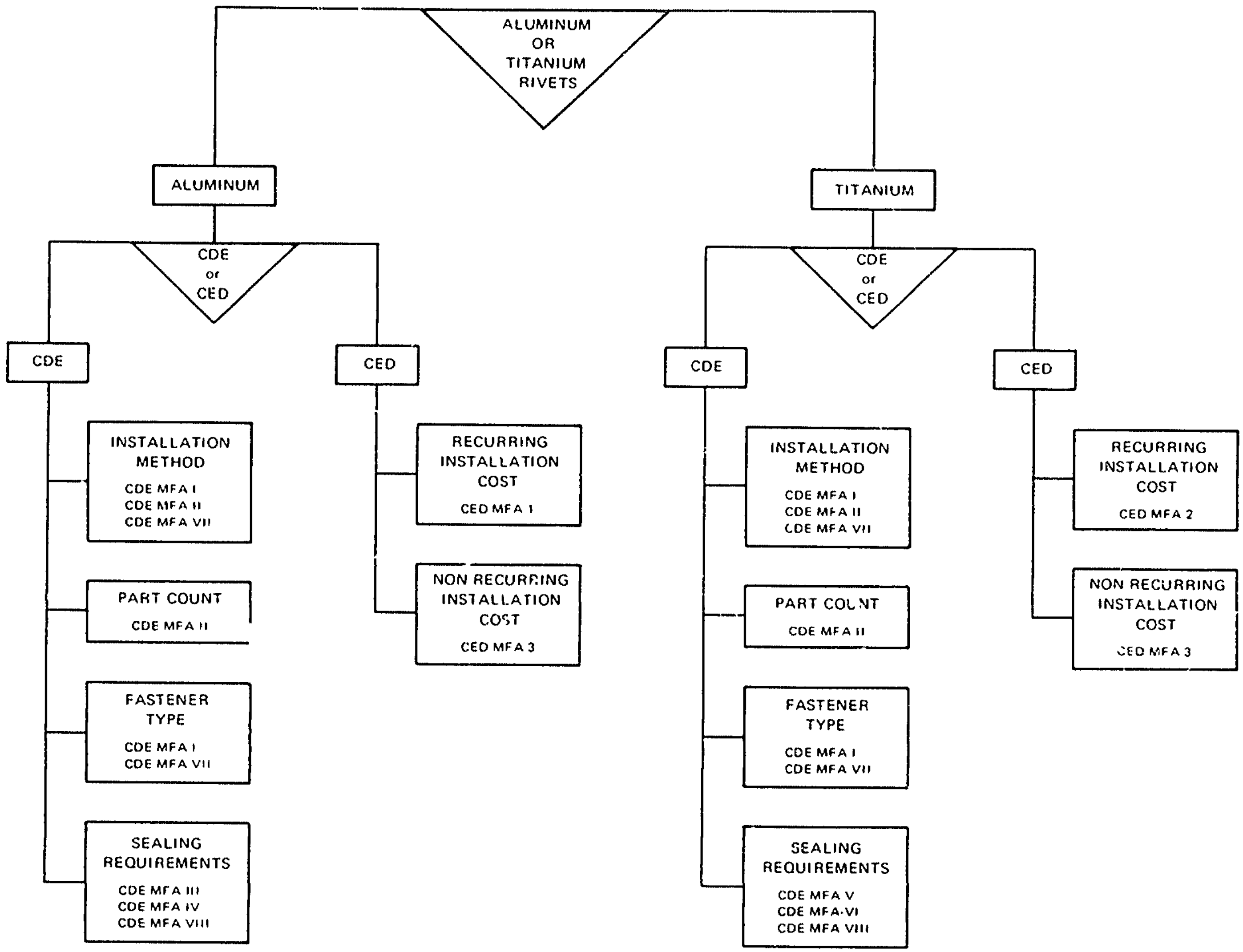
SECTION A-A

FUSELAGE CUT-OUT

"MANUFACTURING COST/DESIGN GUIDE (MC/DG)"

FORMAT SELECTION AID

MECHANICALLY FASTENED ASSEMBLIES



MECHANICALLY FASTENED ASSEMBLIES

DEMONSTRATION SECTION

EXAMPLE OF UTILIZATION

MECHANICALLY FASTENED ASSEMBLIES DEMONSTRATION SECTION (EXAMPLE OF UTILIZATION)

EXAMPLE. MECHANICALLY FASTENED ASSEMBLY

Problem: Determine manufacturing cost (man-hours) for an aluminum (2024) first-level assembly as shown on the sketch on the following page.

(1) Utilize Format Selection Aid for Mechanically Fastened Assemblies.

(2) Determine formats to use. In this case, Formats CED-MFA-1 and CED-MFA-3 are required.

(3) Study formats, determining parameters and conditions necessary for use. To use CED-MFA-1, number of fasteners, fastening method, and sealing requirements must be specified. The sketch indicates 133 fasteners with faying surface sealed. For this example, manual and automatic riveting will be considered. To use CED-MFA-3, the part perimeter (ft) and fastening methods are required. The perimeter is 14.4 ft and again both automatic and manual riveting will be considered by the designer.

(4) Determine the values for recurring cost and non-recurring tooling cost (NRTC) from the formats:

(a) Manual

- Recurring cost at unit 200 = 5.0 man-hours per part
- NRTC = 420 man-hours per 200 parts
  = 2.10 man-hours per part
- Learning curve factor to convert unit cost at 200 to cumulative average cost for an 80% curve and a quantity of 200 is 1.45.

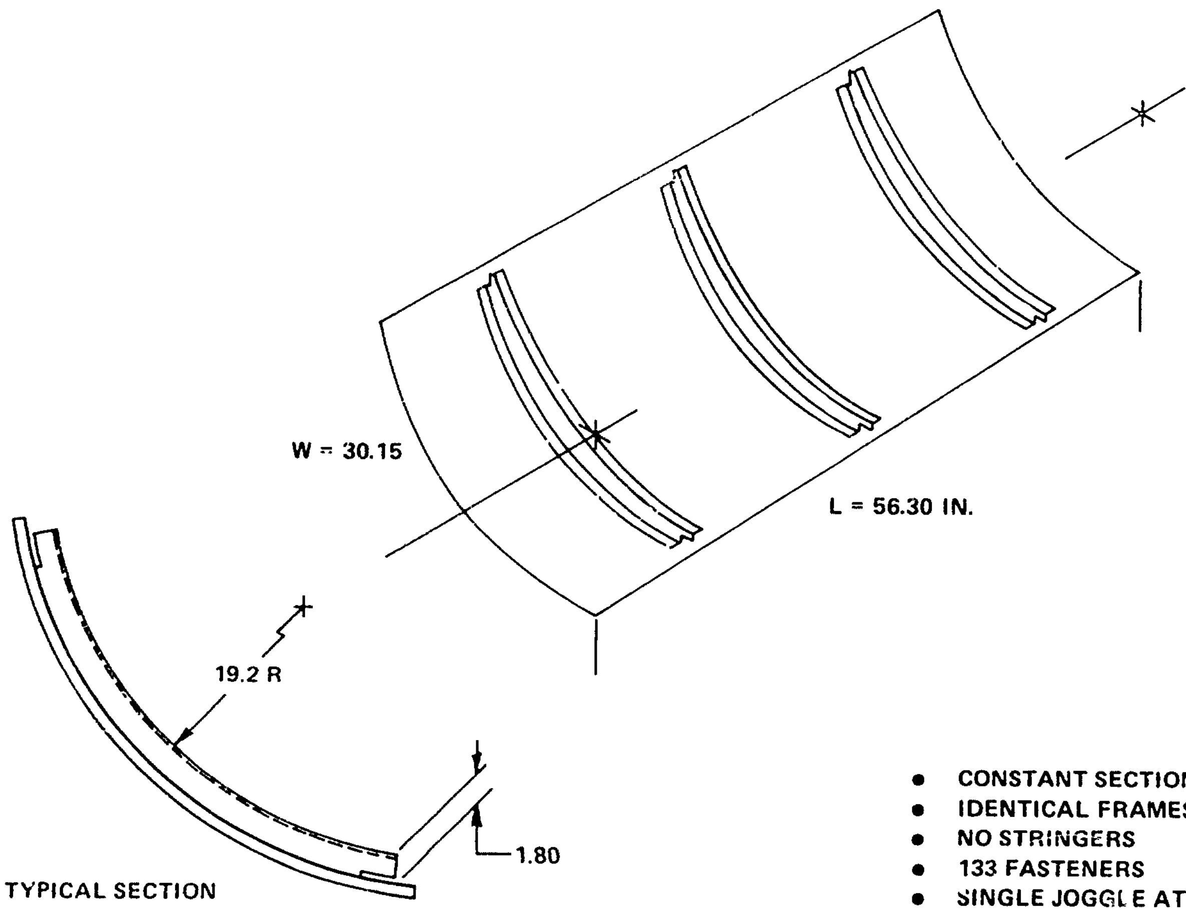
Total cost = 1.45 (5.0) + 2.1 = 9.35 man-hours per part.

(b) Automatic

- Recurring cost at unit 200 = 3.25 man-hours per part
- NRTC = 440 man-hours per 200 parts
  = 2.2 man-hours per part.

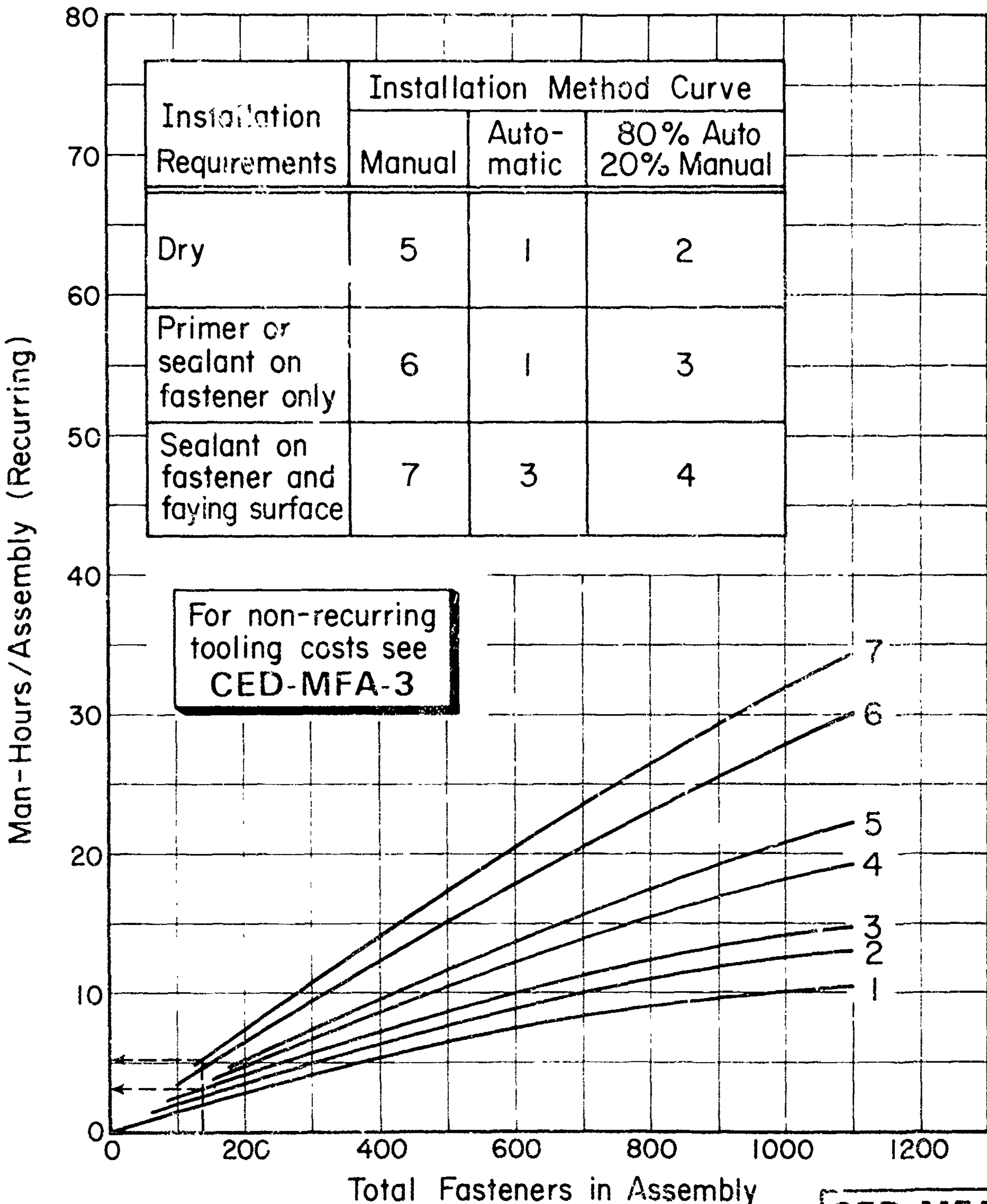
Total cost = 1.45 (3.25) + 2.2 = 6.91 man-hours per part.

(5) Check for applicable DICE. No applicable DICE are indicated, and, therefore, the costs determined in (4) above are the final total costs for assembling the part.



- CONSTANT SECTION RADIUS
- IDENTICAL FRAMES
- NO STRINGERS
- 133 FASTENERS
- SINGLE JOGGLE AT FRAME ENDS
- SEAL FAYING SURFACES

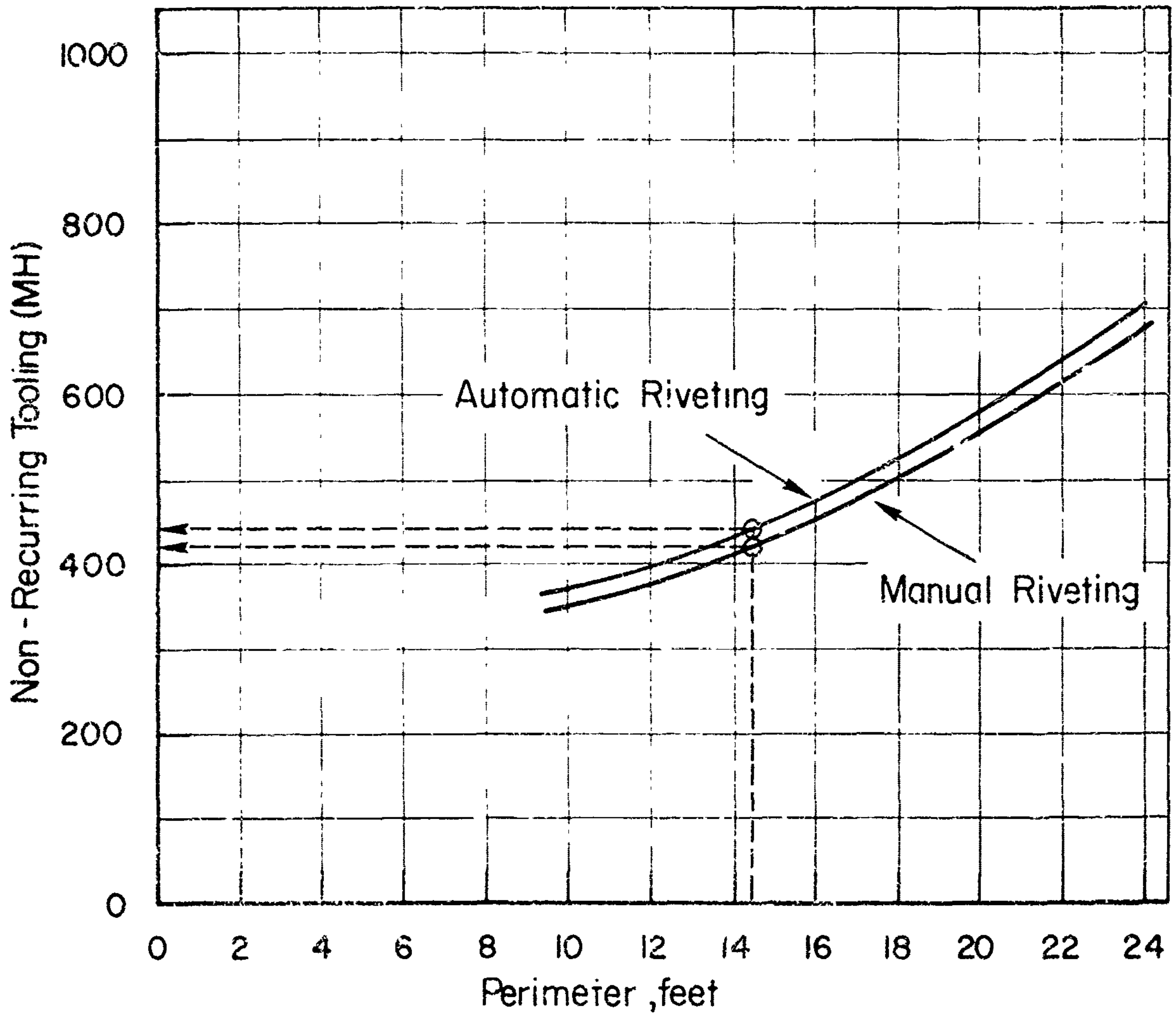
INSTALLATION COSTS FOR ALUMINUM RIVETS



Installation Requirements	Installation Method Curve		
	Manual	Automatic	80% Auto 20% Manual
Dry	5	1	2
Primer or sealant on fastener only	6	1	3
Sealant on fastener and faying surface	7	3	4

CED-MFA-1

NON-RECURRING TOOLING COST FOR
ALUMINUM AND TITANIUM ASSEMBLIES



CED-MFA-3

FORMATS FOR

MECHANICALLY FASTENED ASSEMBLIES

COST-DRIVER EFFECTS (CDE)

FORMATS FOR MECHANICALLY FASTENED ASSEMBLIES
COST-DRIVER EFFECTS (CDE)

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as primer or sealant on fastener and/or faying surface.

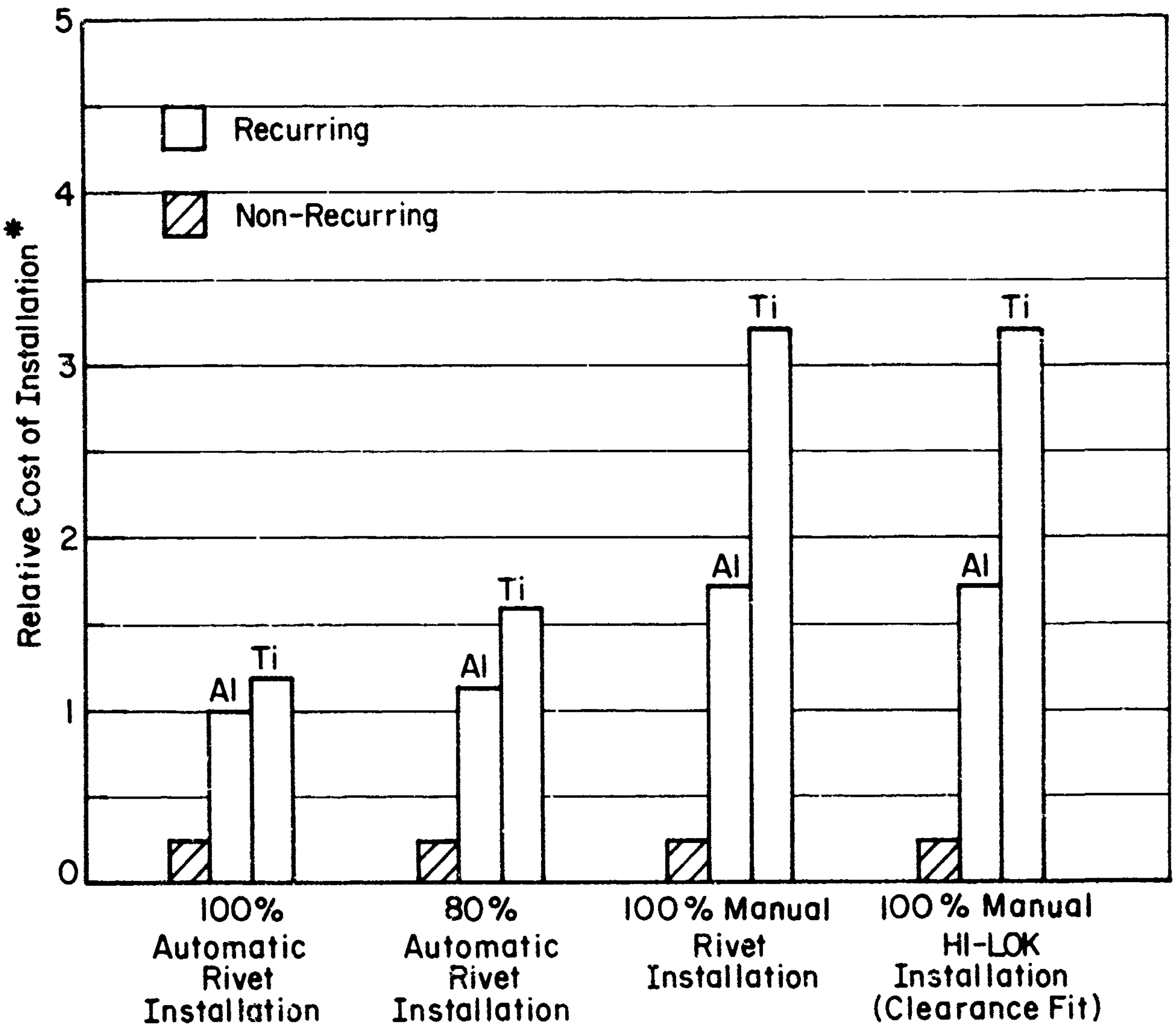
(2) Designer-Influenced Cost Elements (DICE): Includes primer or sealant on fastener and/or faying surface, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 11. FORMATS FOR COST-DRIVER EFFECTS--
MECHANICALLY FASTENED ASSEMBLIES

Format Number	Format Title
CDE-MFA-I	Fastener Installation Costs, Aluminum and Titanium Assemblies: Recurring and Non-Recurring Tooling Costs
CDE-MFA-II	Effect of Part Count and Fastening Method
CDE-MFA-III	Effects of Sealing on Fastener Installation Cost for Aluminum Assemblies
CDE-MFA-IV	Effect of Sealing on Assembly Cost for Aluminum Assemblies
CDE-MFA-V	Effect of Sealing on Fastener Installation Cost for Titanium Assemblies
CDE-MFA-VI	Effect of Sealing on Assembly Cost for Titanium Assemblies
CDE-MFA-VII	Influence on Manufacturing Cost of Installation Method, Assembly Material, and Fastener Type
CDE-MFA-VIII	Effect of Sealing on Fastener Installation Cost for Aluminum and Titanium Assemblies

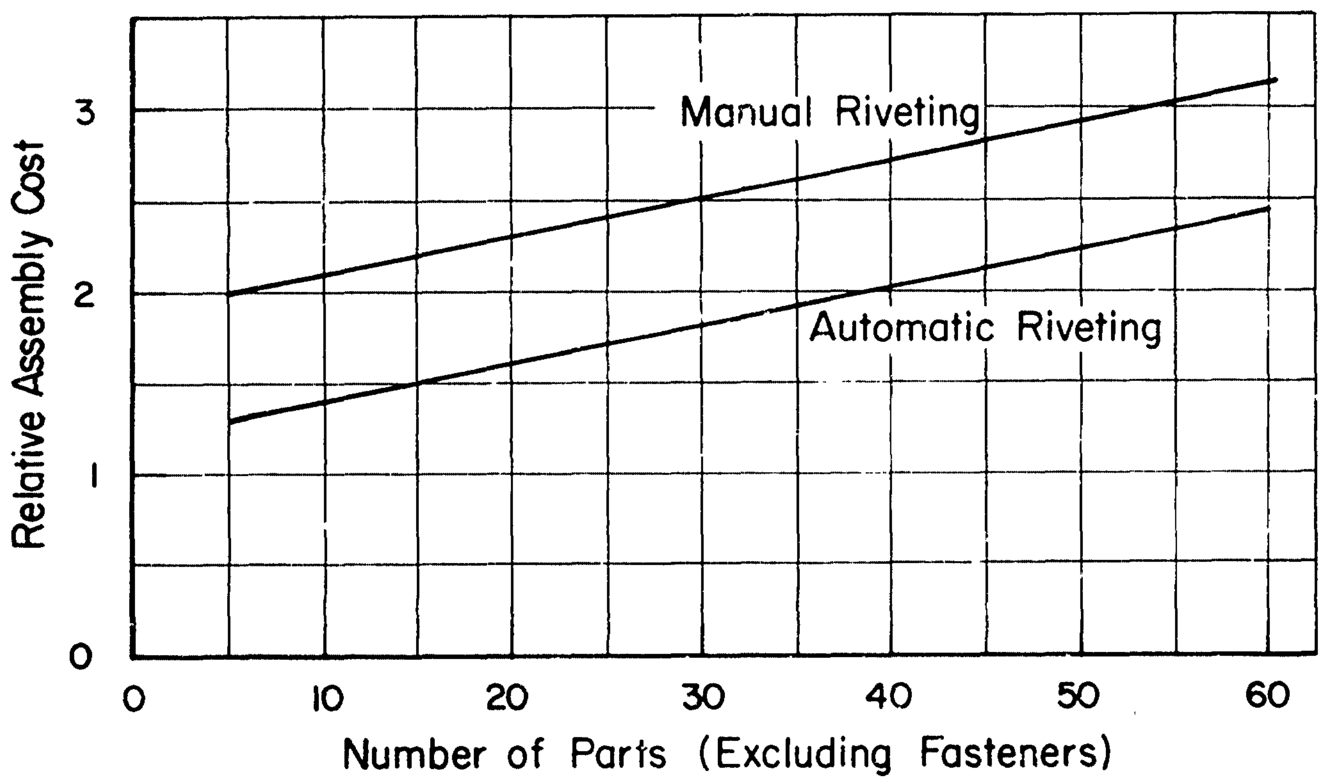
EFFECT OF INSTALLATION METHOD FOR ALUMINUM AND TITANIUM ASSEMBLIES



* Includes the complete operation-hole preparation and fastener setting

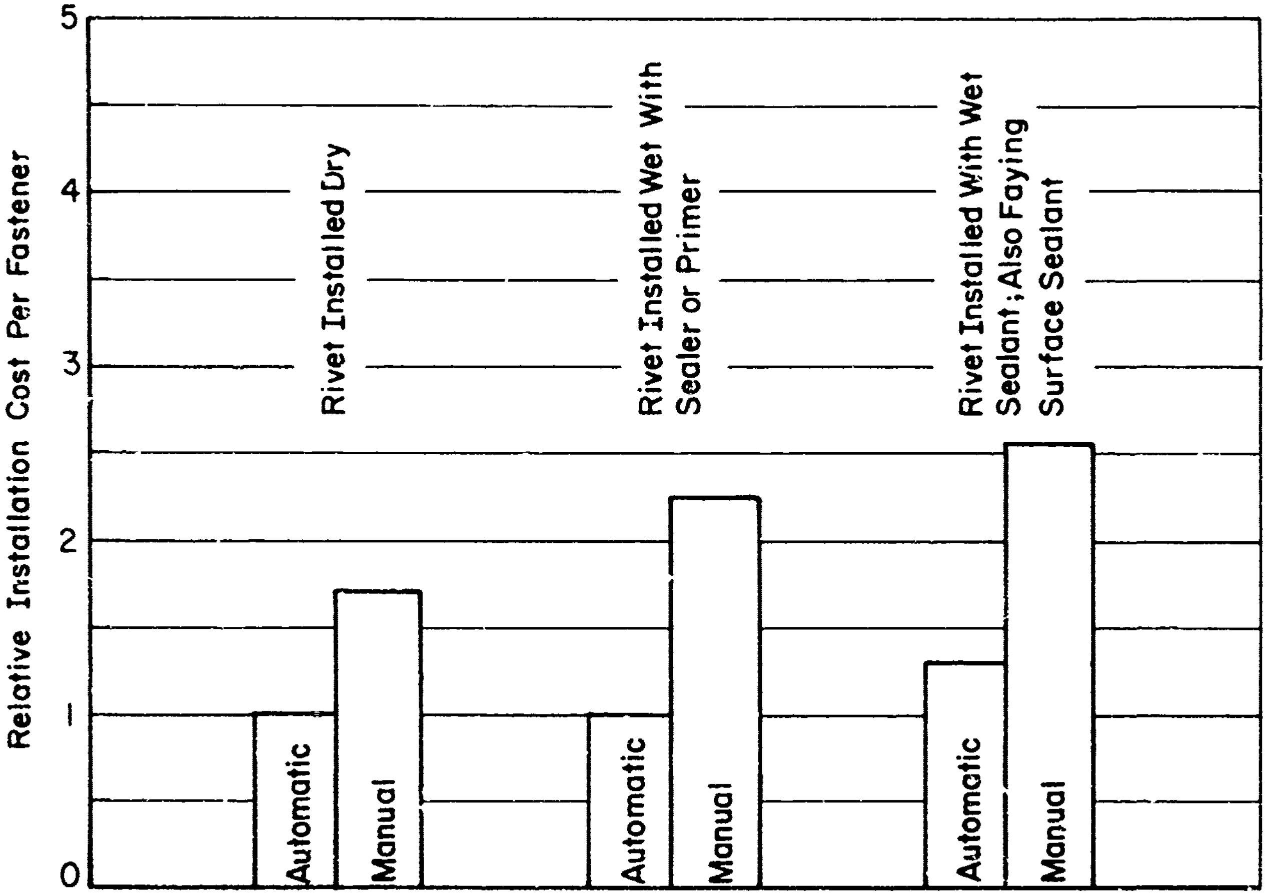
CDE-MFA-I

EFFECT OF PART COUNT AND FASTENING METHOD



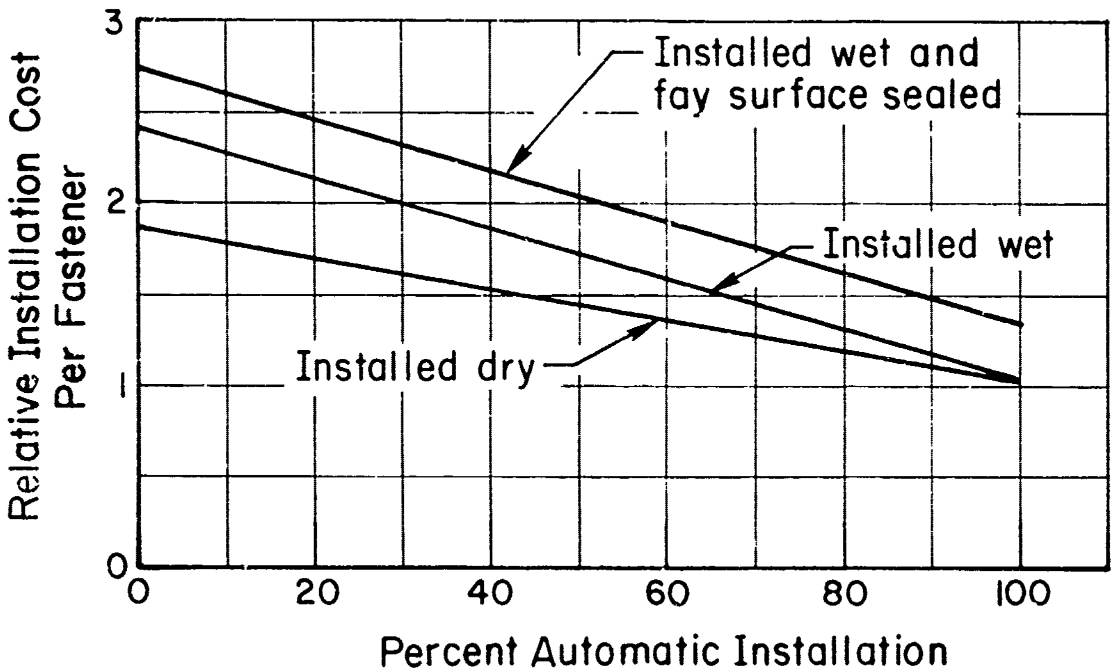
CDE-MFA-II

EFFECTS OF SEALING ON FASTENER INSTALLATION COST
ALUMINUM



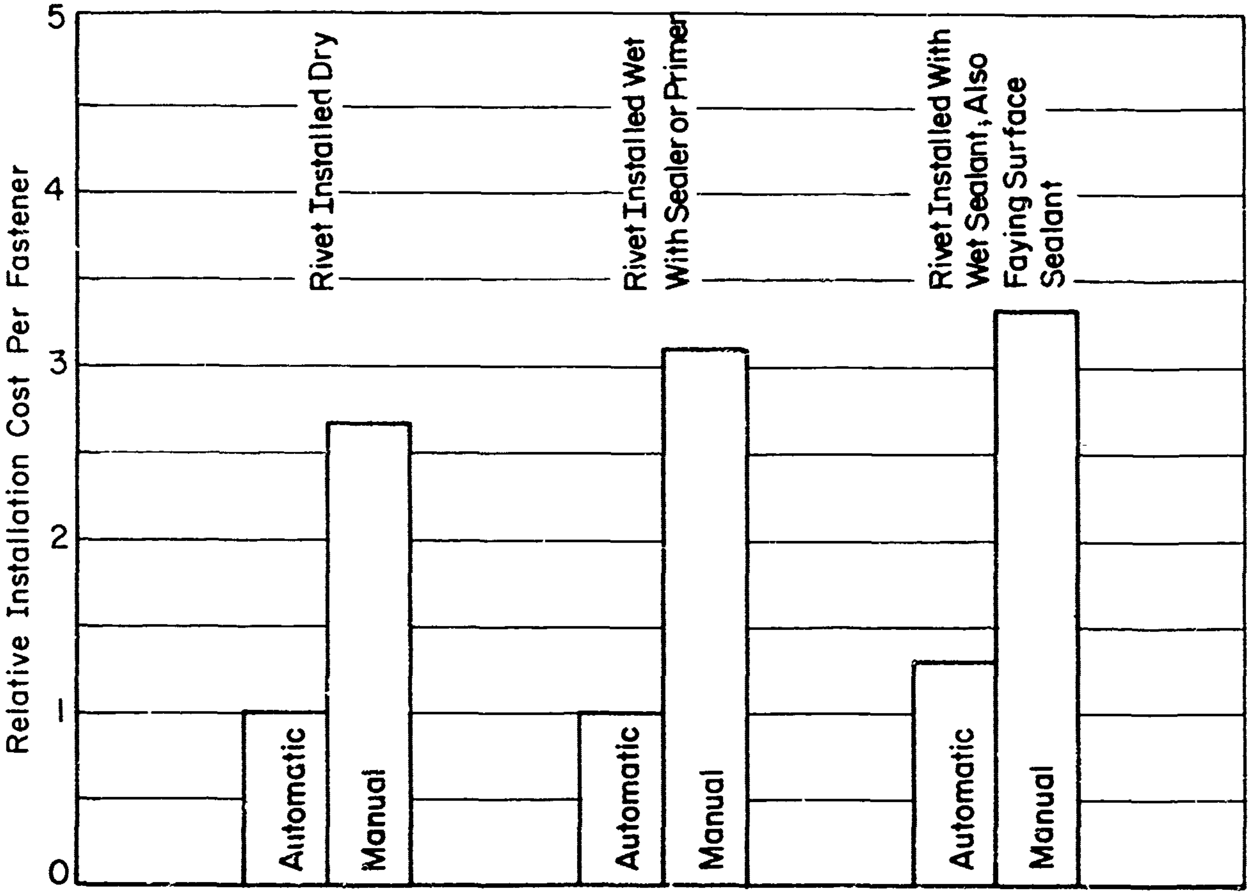
CDE-MFA-III

EFFECT OF SEALING ON ASSEMBLY COST
ALUMINUM ASSEMBLIES



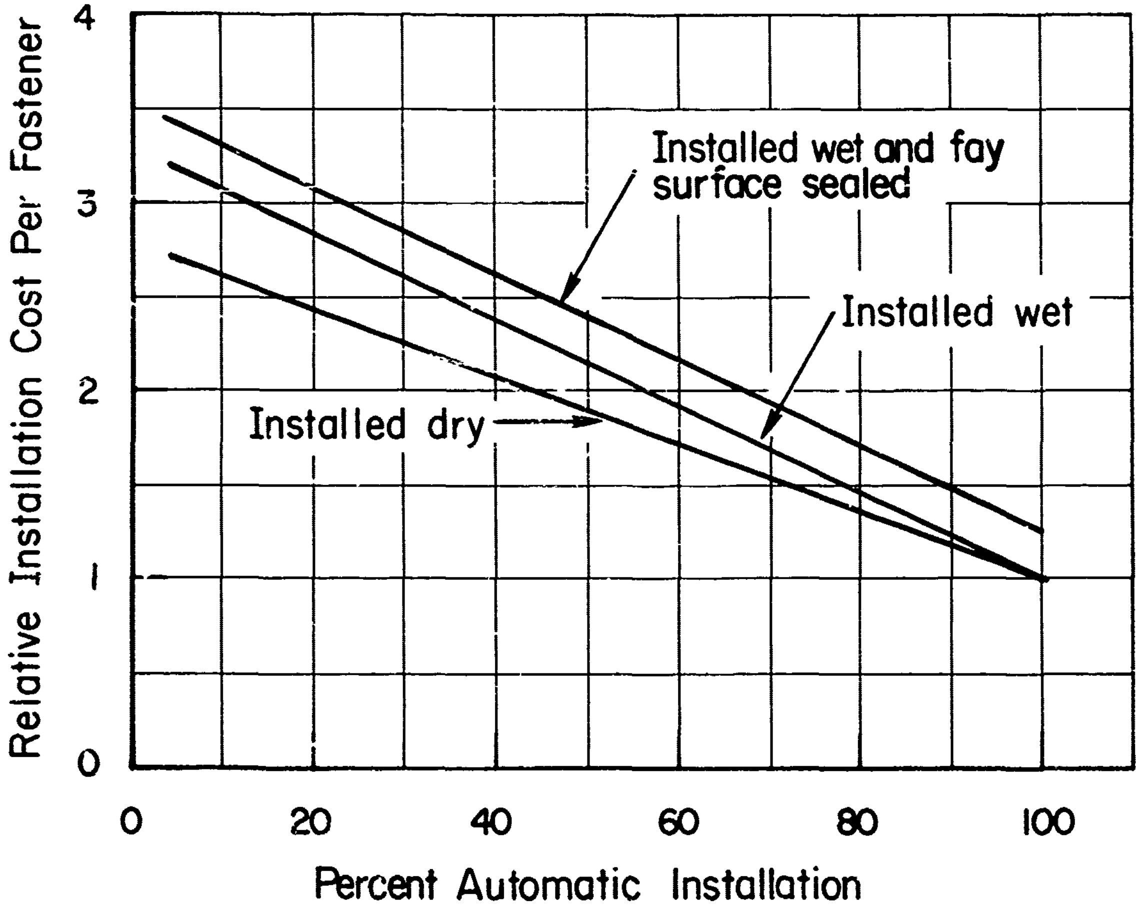
CDE-MFA-IV

EFFECTS OF SEALING ON FASTENER INSTALLATION COST
TITANIUM ASSEMBLIES



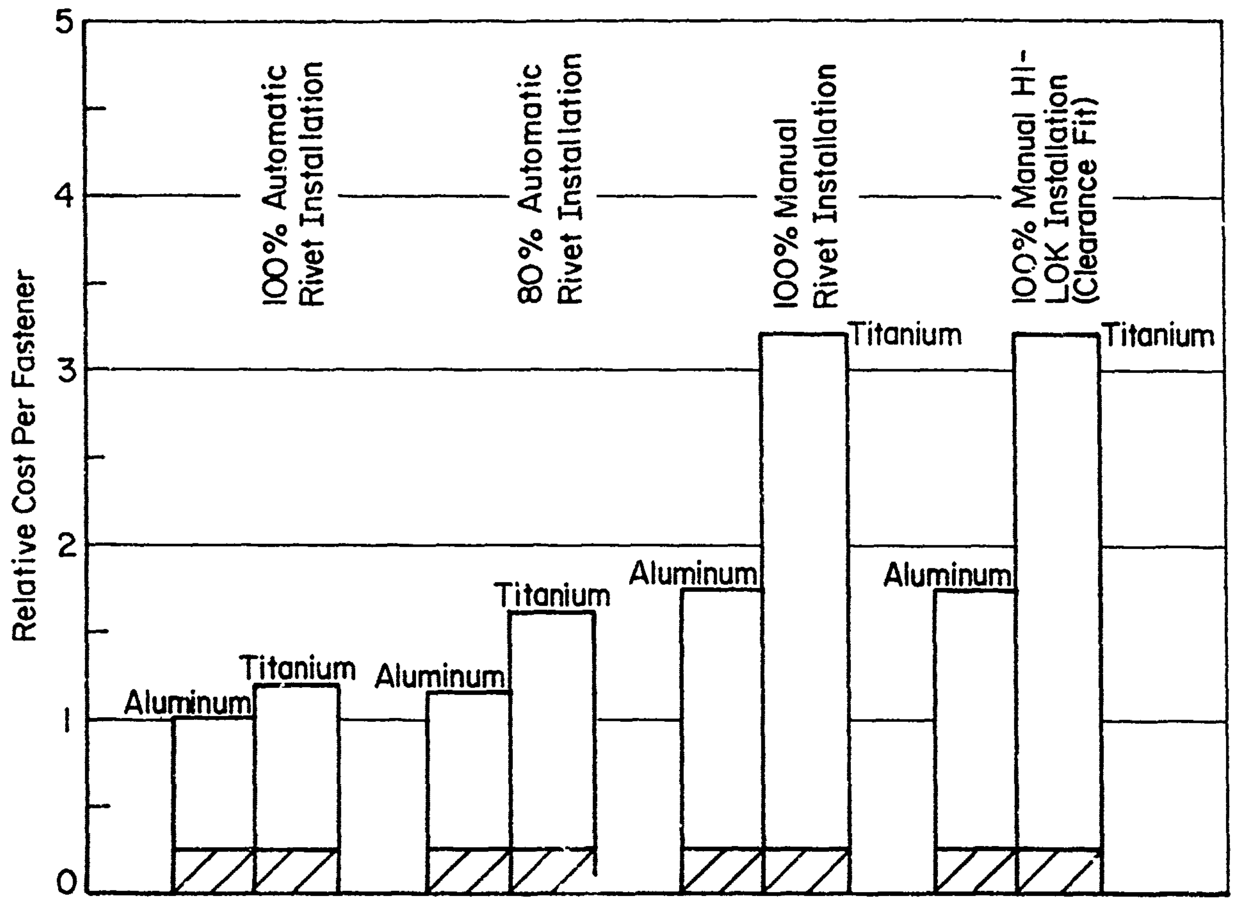
CDE-MFA-V

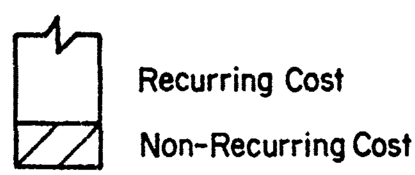
EFFECT OF SEALING ON ASSEMBLY COST
TITANIUM ASSEMBLIES



CDE-MFA-VI

COST EFFECTS OF INSTALLATION* METHOD, ASSEMBLY MATERIAL AND FASTENER TYPE

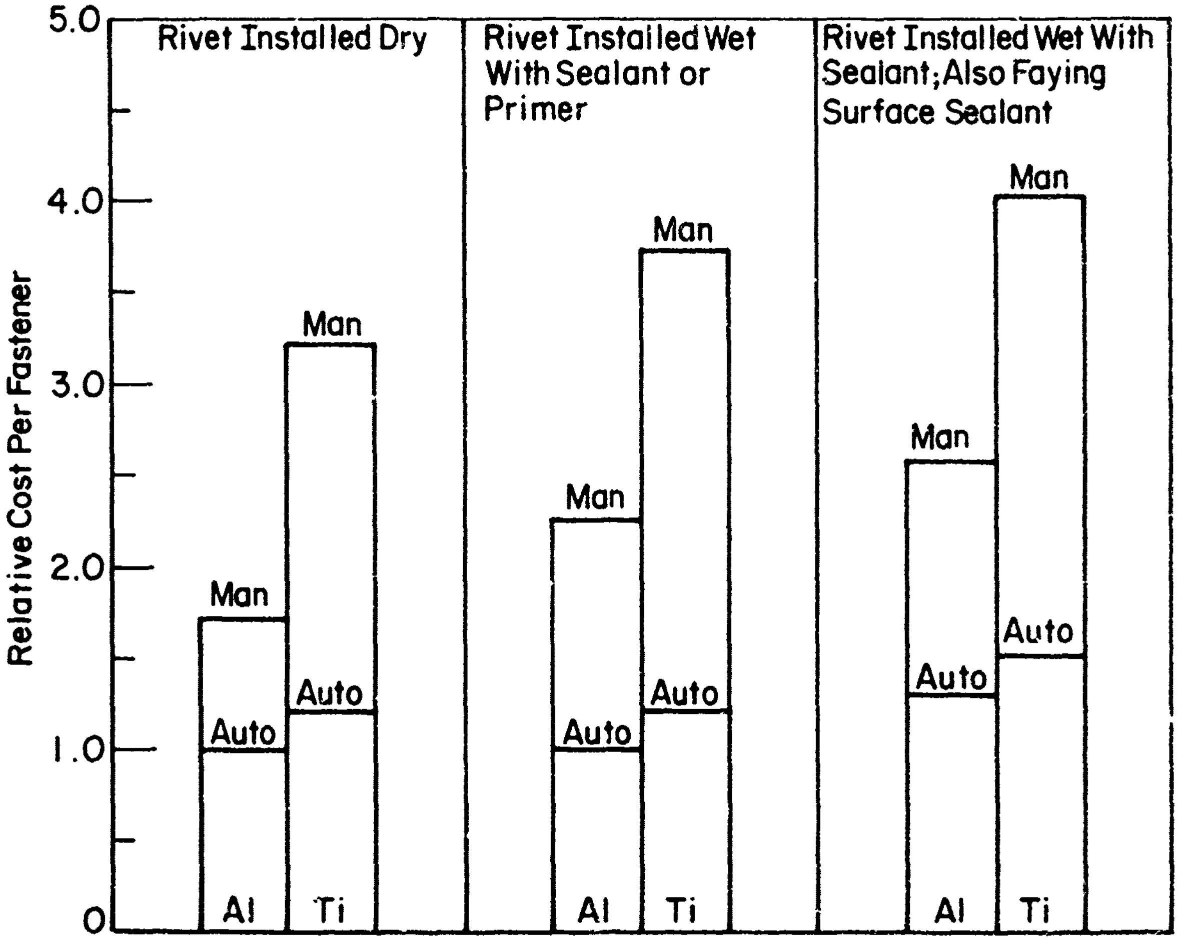




* Installation includes the complete operation-hole preparation and fastener setting

CDE-MFA-VII

EFFECT OF SEALING ON FASTENER INSTALLATION COST: ALUMINUM AND TITANIUM ASSEMBLIES



CDE-MFA-VIII

FORMATS FOR

MECHANICALLY FASTENED ASSEMBLIES

COST-ESTIMATING DATA (CED)

FORMATS FOR MECHANICALLY FASTENED ASSEMBLIES
COST-ESTIMATING DATA (CED)

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as primer or sealant on fastener and/or faying surface.

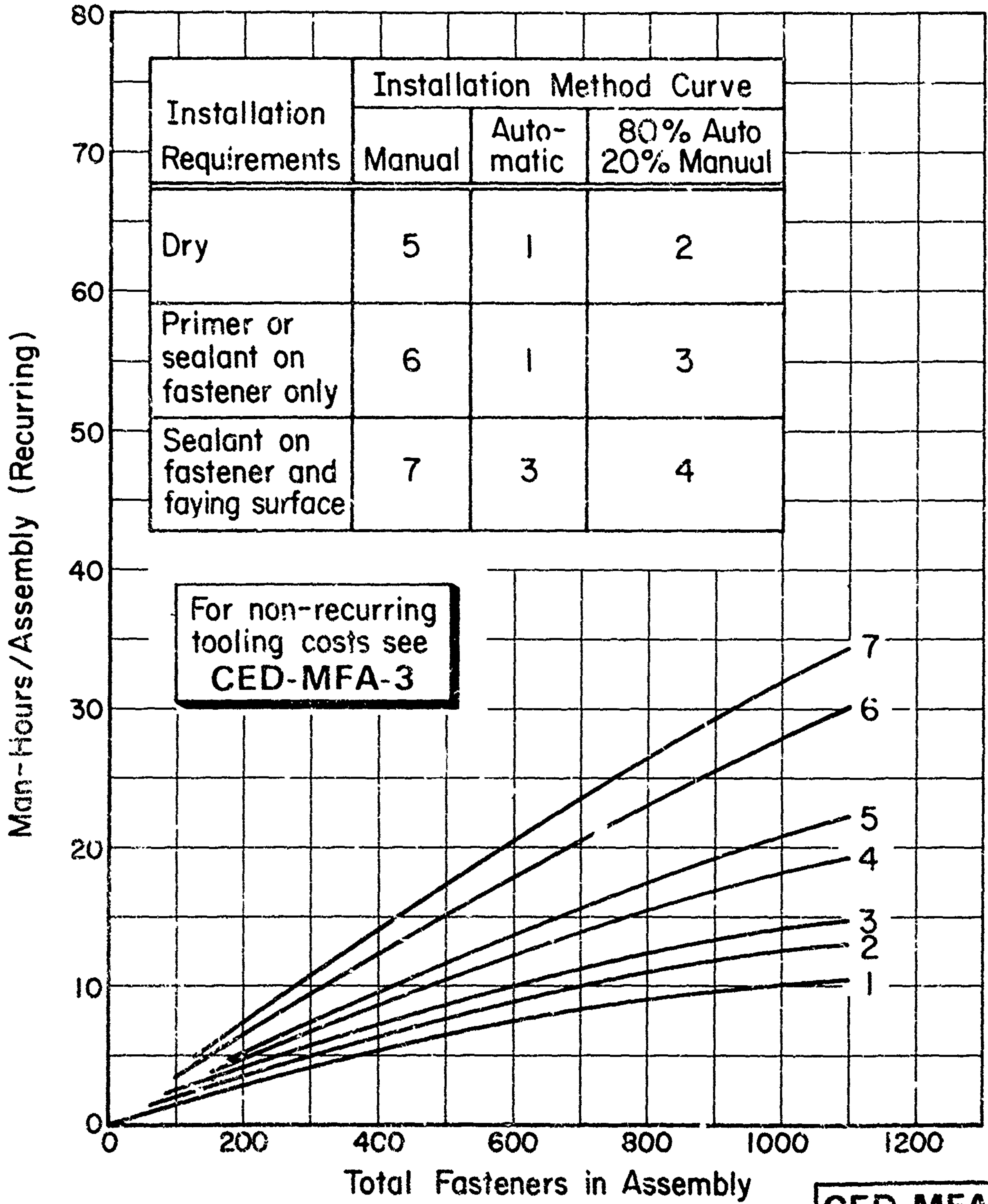
(2) Designer-Influenced Cost Elements (DICE): Includes primer or sealant on fastener and/or faying surface, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 12. FORMATS FOR COST-ESTIMATING DATA—MECHANICALLY FASTENED ASSEMBLIES

Format Number	Format Title
CED-MFA-1	Installation Costs for Aluminum Rivets
CED-MFA-2	Installation Costs for Titanium Rivets
CED-MFA-3	Non-Recurring Tooling Cost for Aluminum and Titanium Assemblies

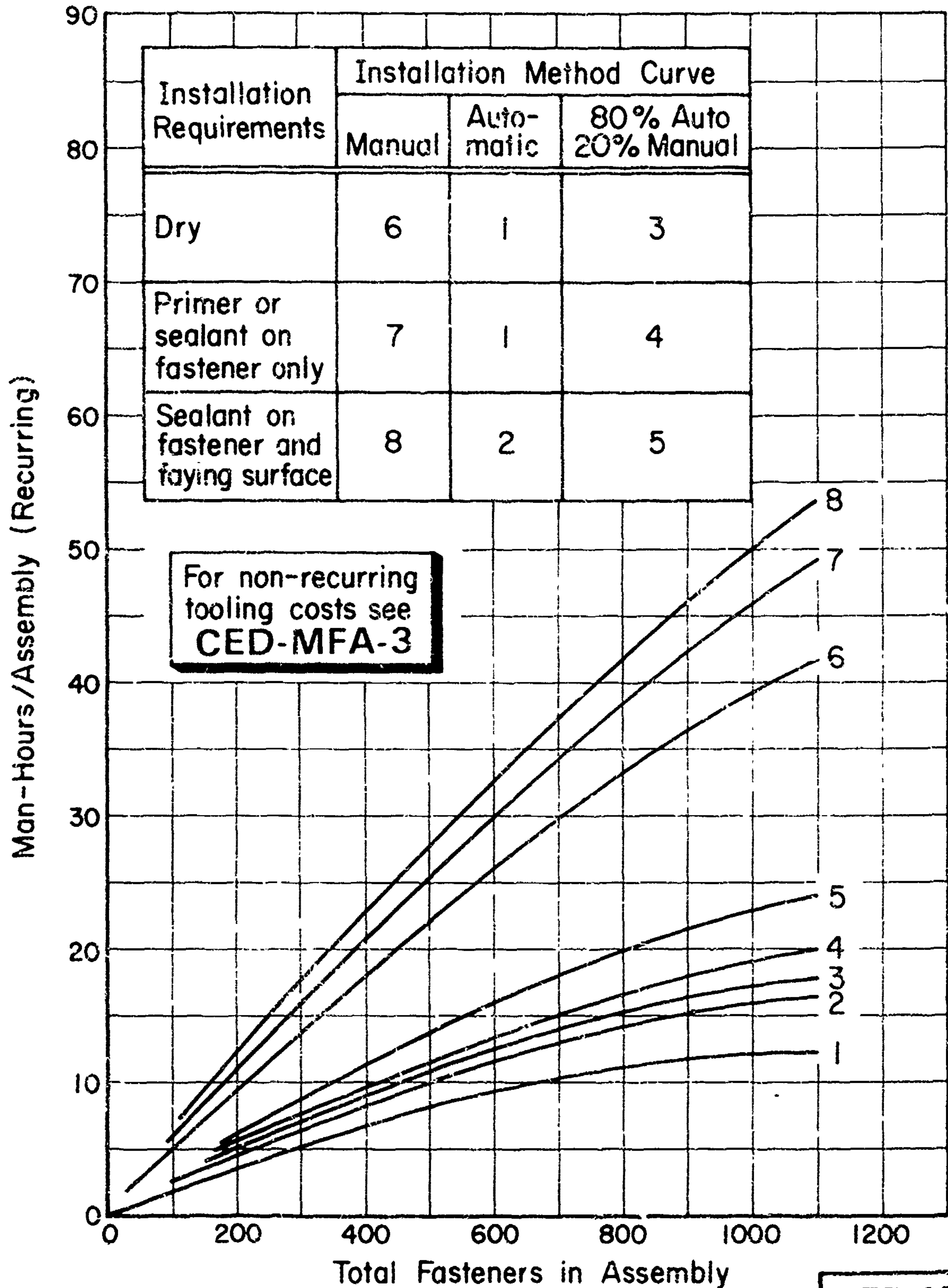
INSTALLATION COSTS FOR ALUMINUM RIVETS



Installation Requirements	Installation Method Curve		
	Manual	Automatic	80% Auto 20% Manual
Dry	5	1	2
Primer or sealant on fastener only	6	1	3
Sealant on fastener and faying surface	7	3	4

CED-MFA-1

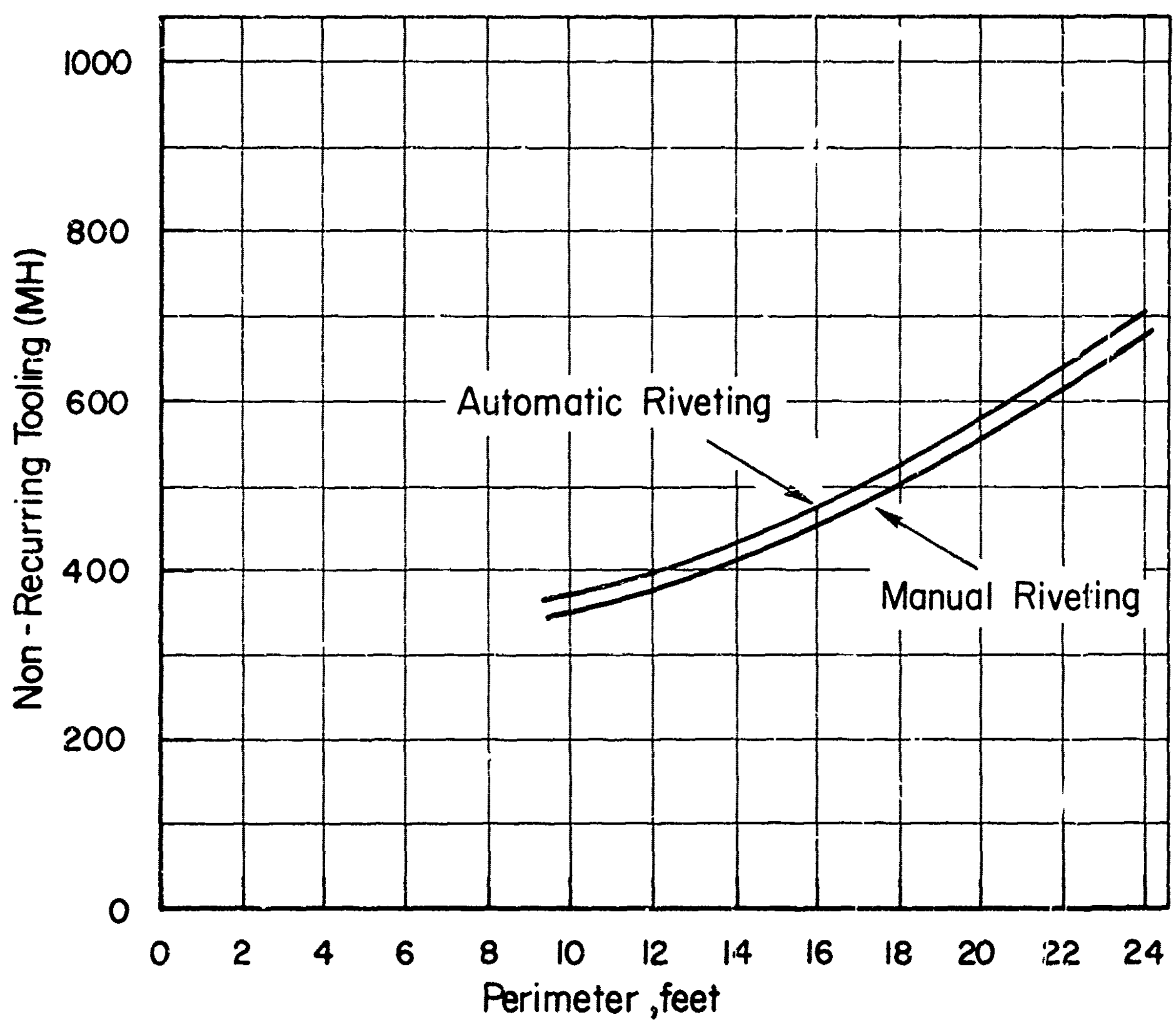
INSTALLATION COSTS FOR TITANIUM RIVETS



Installation Requirements	Installation Method Curve		
	Manual	Automatic	80% Auto 20% Manual
Dry	6	1	3
Primer or sealant on fastener only	7	1	4
Sealant on fastener and faying surface	8	2	5

CED-MFA-2

NON-RECURRING TOOLING COST FOR ALUMINUM AND TITANIUM ASSEMBLIES



CED-MFA-3

SECTION IX

ADVANCED COMPOSITE FABRICATION DEMONSTRATION SECTION

Advanced composite materials, in particular, graphite/epoxy, have demonstrated remarkable service performance in aircraft primary structures on the F-14, F-15, F-16, and other aircraft. A significant example of the use of advanced composites is the movable horizontal stabilizer. Advanced composites are now rapidly emerging as a primary candidate material for application in the next generation aircraft. Management and designers are, therefore, making commitments to manufacture complete wings in these fibrous materials. The trends suggest that the next generation aircraft could contain from 30 to 50 percent of advanced composite materials.

There are a number of important opportunities where composites not only provide greatly improved structural efficiency in terms of strength, stiffness, life time, and, therefore, lower weight than metallic structures, but also cost reduction particularly due to the increasing cost of strategic metallic materials and also for complex structural configurations, such as fuselages of compound curvature, where advanced composites are becoming increasingly cost competitive. The following payoffs or improvements appear realistic for aft fuselage structures:

- Weight savings: 20-30 percent
- Cost savings: 15-25 percent
- Life extensions projected
- Improved reliability projected
- Improved maintainability projected.

Now that management and designers are confident with the use of composite materials based on the outstanding performance to date, it is timely to develop an MC/DG Demonstration Section for "Advanced Composites Fabrication", meeting the MC/DG objectives identified in the introduction to this report.

Designers need to compare composite materials with aluminum, steel, and titanium sheet candidates for many airframe components. The demonstration section or advanced composites can be utilized in trade studies comparing manufacturing cost of sheet metal with composites based on similar ground rules and conditions and, therefore, providing the required credibility of the comparisons, which is most important. Furthermore, the designer will want to develop not only more, but larger, structures designed as a complete structural system rather than replacing metals with composites under severe limitations, i.e., meeting Form, Fit, and Function requirements. While the Advanced Composites Fabrication Guide (ACFG) and the Advanced Composites Cost Estimating Manuals (ACCEM) are extremely important milestones in the development and utilization of composite structures, it was evident that designer oriented tools meeting these special design criteria of the MC/DG are urgently required to supplement these other data sources as accomplished with sheet metal materials.

In AFML-TR-76-227, "Manufacturing Cost/Design Guide", the cost drivers were analyzed for fiberglass materials and also designer-oriented formats were proposed. This section for composites in the MC/DG "model", recommended under the prior program, was reviewed by the team and the following cost drivers were specified for advanced composite materials:

- Fiber types
- Resin systems
- Fiber mix (hybrids)
- Part function
- Part type
- Part size
- Lot size
- Number of plies
- Orientation of plies
- Overlaps
- Gaps and cut-outs
- Facilities
  - Cocuring
  - Staged assembly
  - Manual lamination
  - Automatic lamination
- Tooling concepts
- Quality requirements.

ADVANCED COMPOSITE FABRICATION

DEMONSTRATION SECTION

ADVANCED COMPOSITE FABRICATION DEMONSTRATION SECTION

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"MANUFACTURING COST/DESIGN GUIDE (MC/DG)"

ADVANCED COMPOSITES FABRICATION

COST–DRIVERS

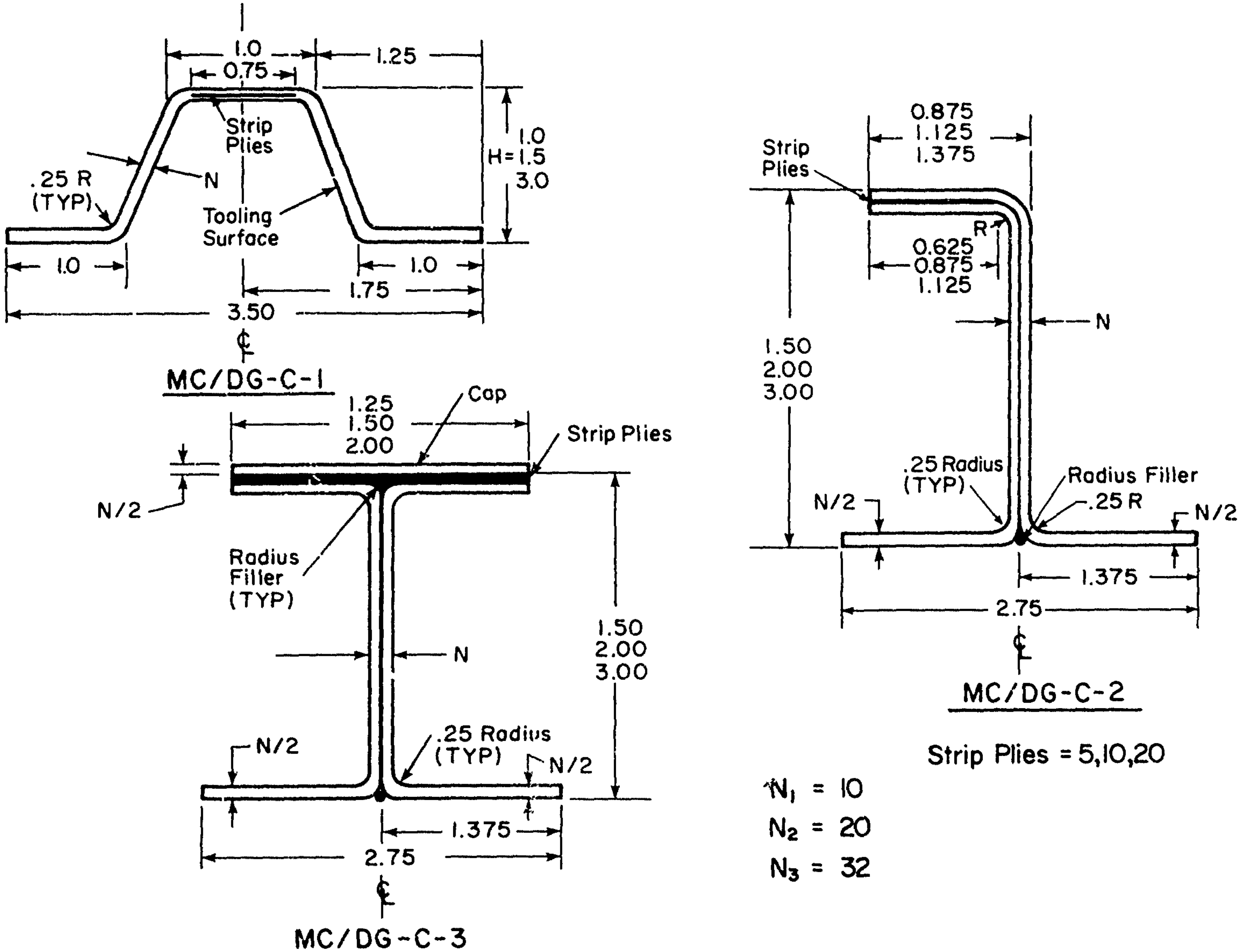
- PART TYPE AND FUNCTION
- PART SIZE
- NUMBER OF PLIES
- ORIENTATION OF PLIES
- OVERLAPS
- GAPS
- LOT SIZE
- FIBER TYPES
- RESIN SYSTEM
- FIBER MIX (HYBRIDS)
- QUALITY REQUIREMENTS
- COCURED VERSUS STAGED ASSEMBLY
- AUTOMATIC VERSUS MANUAL LAMINATION
- FACILITIES
- TOOLING CONCEPT

ADVANCED COMPOSITE FABRICATION

DEMONSTRATION SECTION

PARTS ANALYZED

COMPOSITE LINEAL SHAPES USED TO DEVELOP FORMATS (INFORMATION ONLY)



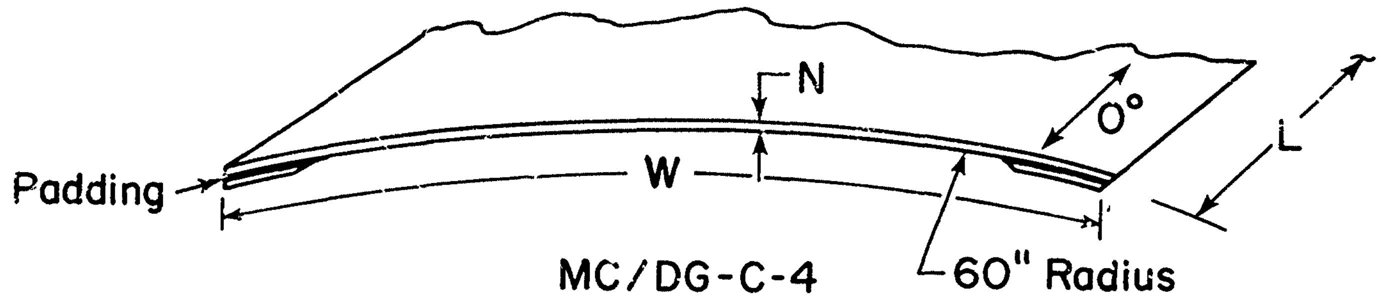
Strip Plies = 5,10,20

$N_1 = 10$

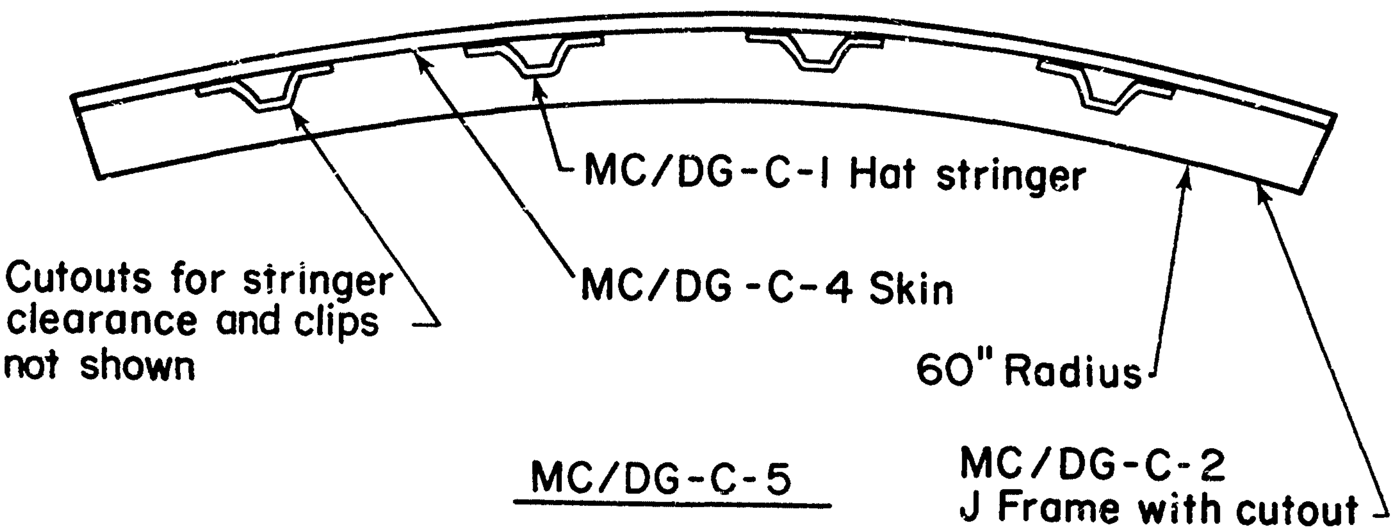
$N_2 = 20$

$N_3 = 32$

COMPOSITE PANEL STRUCTURES



MC/DG-C-4

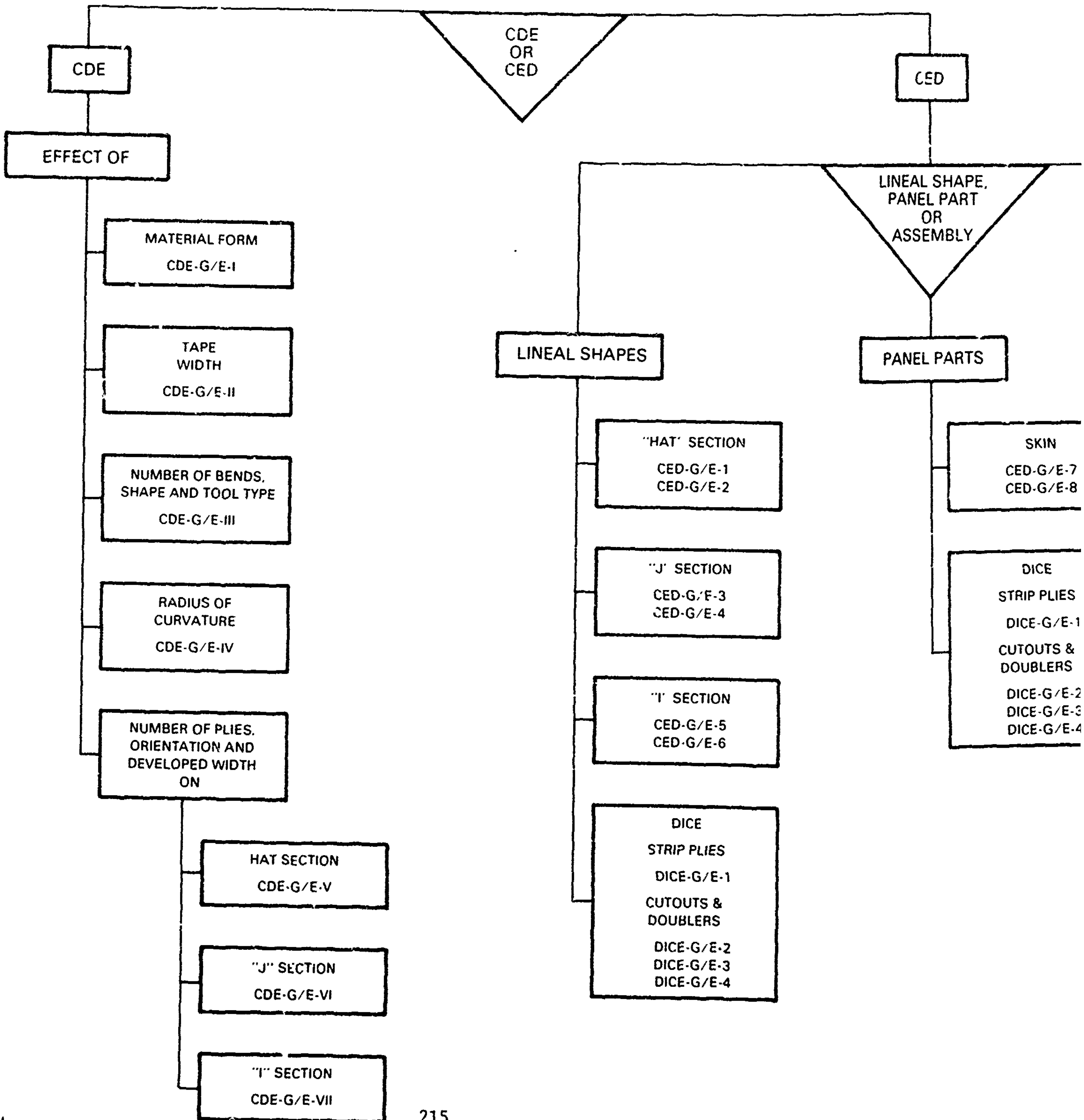


MC/DG-C-5

"MANUFACTURING COST/DESIGN GUIDE (MC/DG)"

FORMAT SELECTION AID

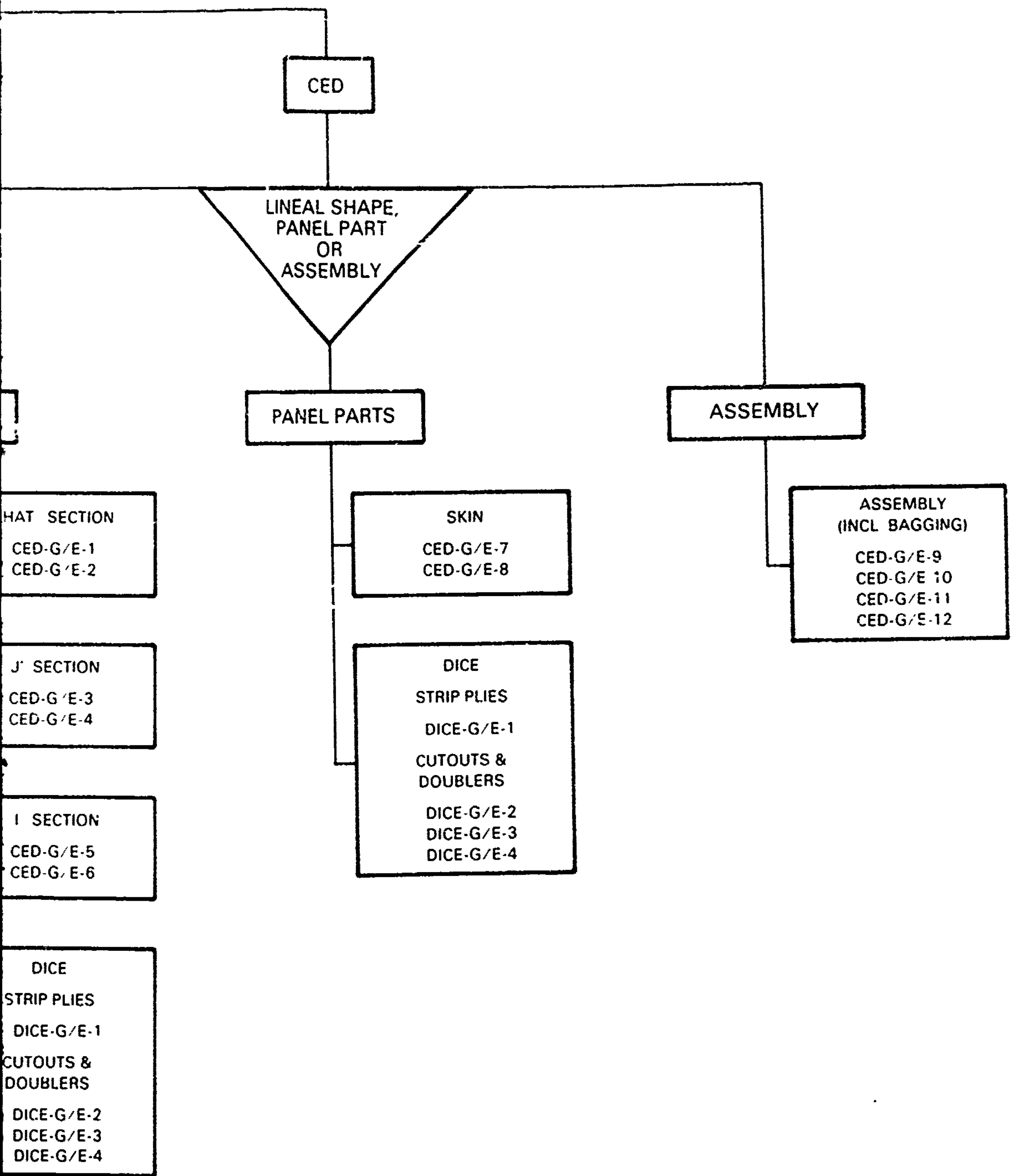
ADVANCED COMPOSITE FABRICATION



E (MC 'DG)''

AID

CATION



2

ADVANCED COMPOSITES FABRICATION

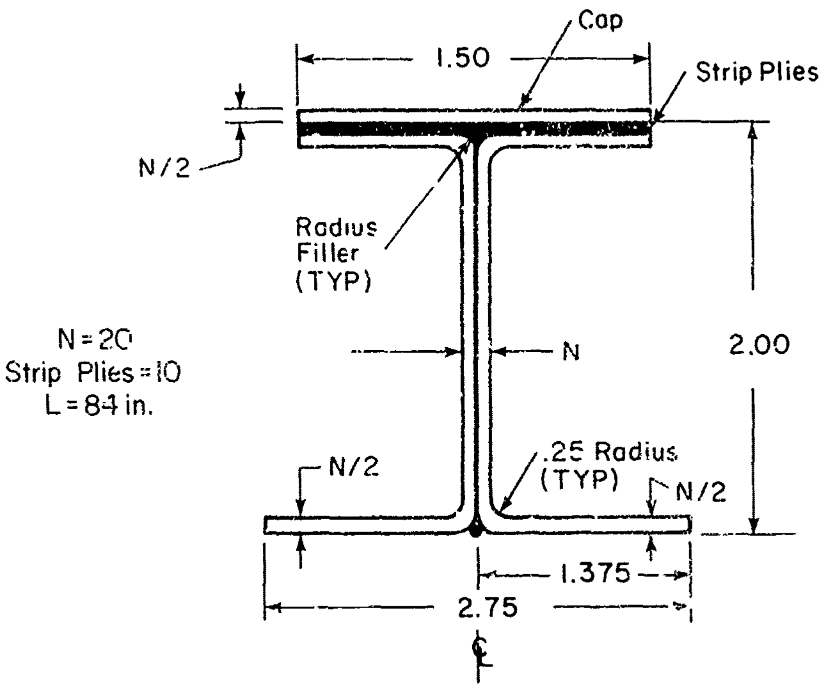
DEMONSTRATION SECTION

EXAMPLE OF UTILIZATION

ADVANCED COMPOSITES FABRICATION DEMONSTRATION SECTION
(EXAMPLE OF UTILIZATION)

EXAMPLE. GRAPHITE/EPOXY "I" SECTION

Problem: Determine manufacturing cost (man-hours) for the composite "I" section shown below, in "B" stage condition. The non-recurring tooling costs are to be amortized for 200 parts.

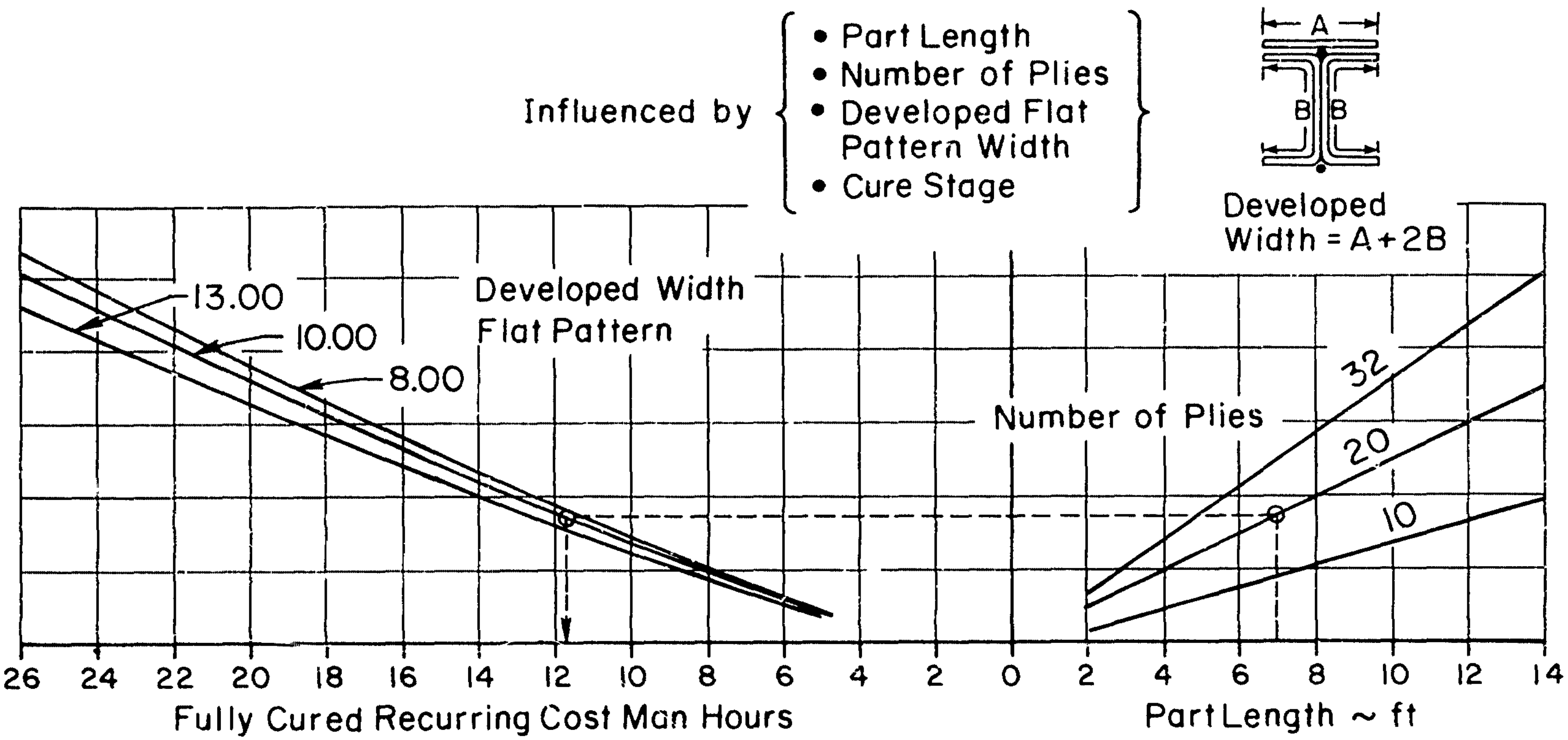


(1) Utilize Format Selection Aid for Advanced Composites.

(2) Determine which formats are required. In this case, CED-G/E-5 and CED-G/E-6 are used.

(3) Study formats to determine parameters and conditions required for use. Format CED-G/E-5 requires part length (ft), number of plies, developed width of the flat pattern (in), and cure stage. Format CED-G/E-6 requires part length (ft) and developed width (in). For this example, part length is 7 ft, number of plies is 20, developed width is 9.75 in., and it is in "B" stage cure.

COMPOSITE I SECTION RECURRING COST/PART



(For "B" Stage Recurring Cost, Multiply by 0.84)

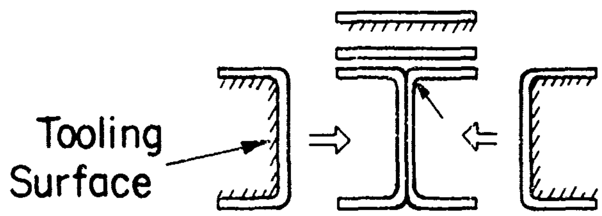
See Ground Rules for Limitations and Considerations

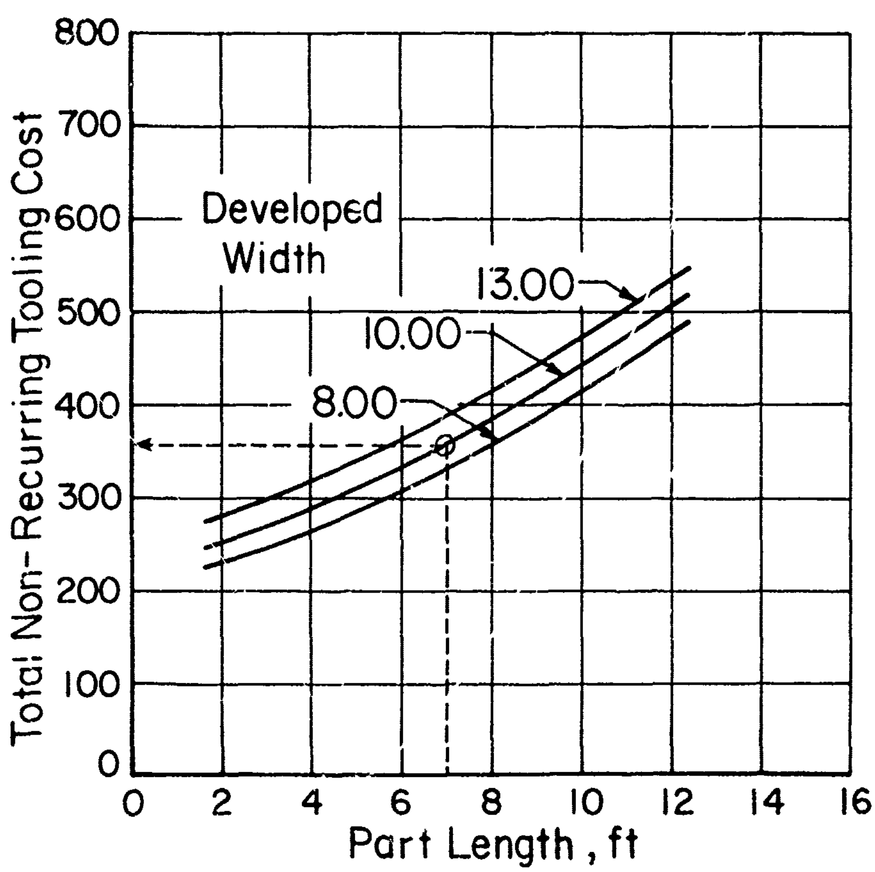
CED-G/E-5

COMPOSITE I SECTION

TOTAL NON-RECURRING TOOLING COST/PART

Influenced By { • Part Length • Developed Width }





See Ground Rules for Limitations and Considerations

CED-G/E-6

(4) Using CED-G/E-5 and CED-G/E-6, determine the recurring cost and non-recurring tooling cost (NRTC) for the part.

- Recurring cost at unit 200 = 11.5 x 0.84 = 9.66 man-hours per part
- NRTC = 360 man-hours = 1.80 man-hours per part
- Learning curve factor to convert unit 200 to cumulative average cost for an 85% learning curve and a quantity of 200: 1.30.

The base part cost, thus, is: 9.66 (1.30) + 1.80 = 14.36 man-hours per part.

(5) Checking for applicable DICE. This part has strip plies. The Format Selection Aid indicates that format DICE-G/E-1 must be used. This format requires length (ft), number of plies, and width (in.) of each ply. These values are:

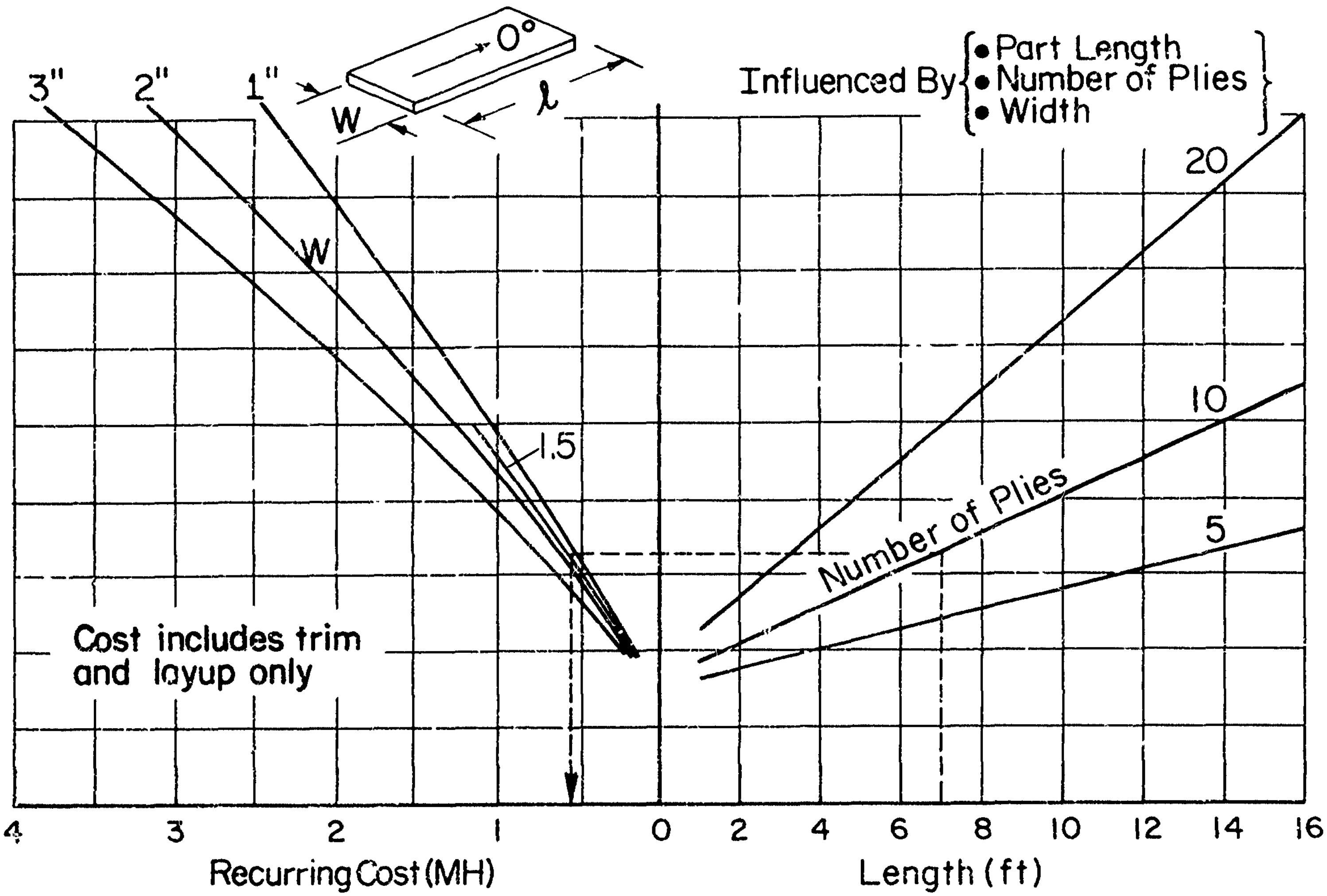
- Length = 7 ft
- Number of plies = 10
- Width = 1.5 in.

From the format, the cost of the strip plies is 0.6 man-hours per part.

The total manufacturing cost for the part (excluding direct material cost) is, therefore, 14.36 + (0.6) 1.30 = 15.14 man-hours per part.

STRIP PLIES (FLAT PARTS) FOR COCURING

RECURRING COST/PART



SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-1

FORMATS FOR

ADVANCED COMPOSITE FABRICATION

COST-DRIVER EFFECTS (CDE)

FORMATS FOR ADVANCED COMPOSITE FABRICATION
COST-DRIVER EFFECTS (CDE)

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as strip-plies, cut-outs, and doublers.

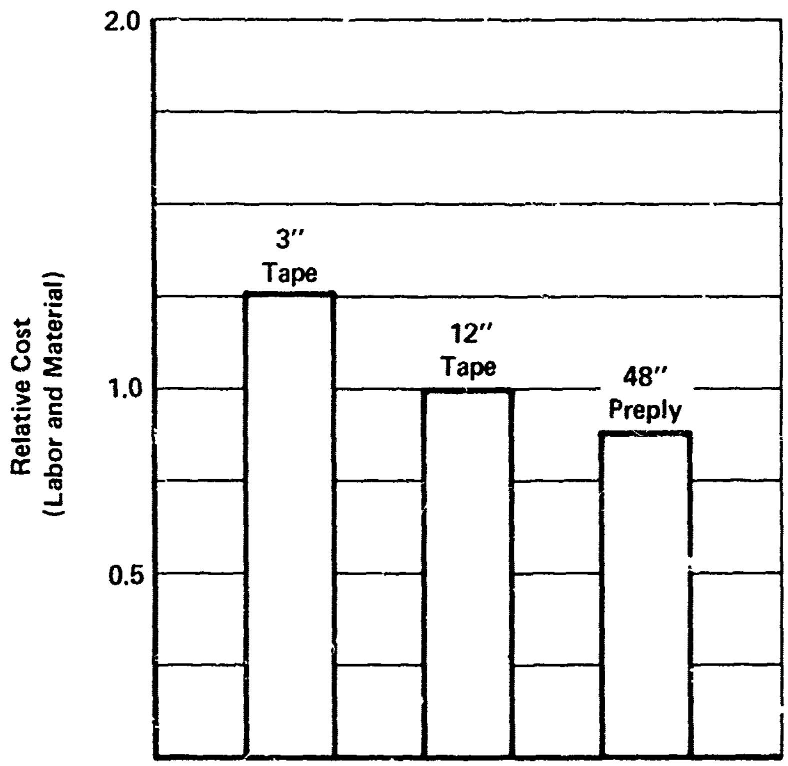
(2) Designer-Influenced Cost Elements (DICE): Includes strip-plies, cut-outs, doublers, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 13. FORMATS FOR COST-DRIVER EFFECTS--
ADVANCED COMPOSITES

Format Number	Format Title
CDE-G/E-I	Effect of Material Form on Layup Cost
CDE-G/E-II	Effect of Tape Width on Cost of Lineal Shapes
CDE-G/E-III	Effect of Number of Bends, Shape, and Tool Type on Tooling Cost of Lineal Shapes
CDE-G/E-IV	Effect of Radius of Curvature on Recurring Cost of Lineal Shapes
CDE-G/E-V	Effect of Number of Plies, Ply Orientation, and Developed Width on Recurring Cost of Lineal Hat Section
CDE-G/E-VI	Effect of Number of Plies, Ply Orientation, and Developed Width on Recurring Cost of Lineal "J" Section
CDE-G/E-VII	Effect of Number of Plies, Ply Orientation, and Developed Width on Recurring Cost of Lineal "I" Section

EFFECT OF MATERIAL FORM ON LAYUP COST



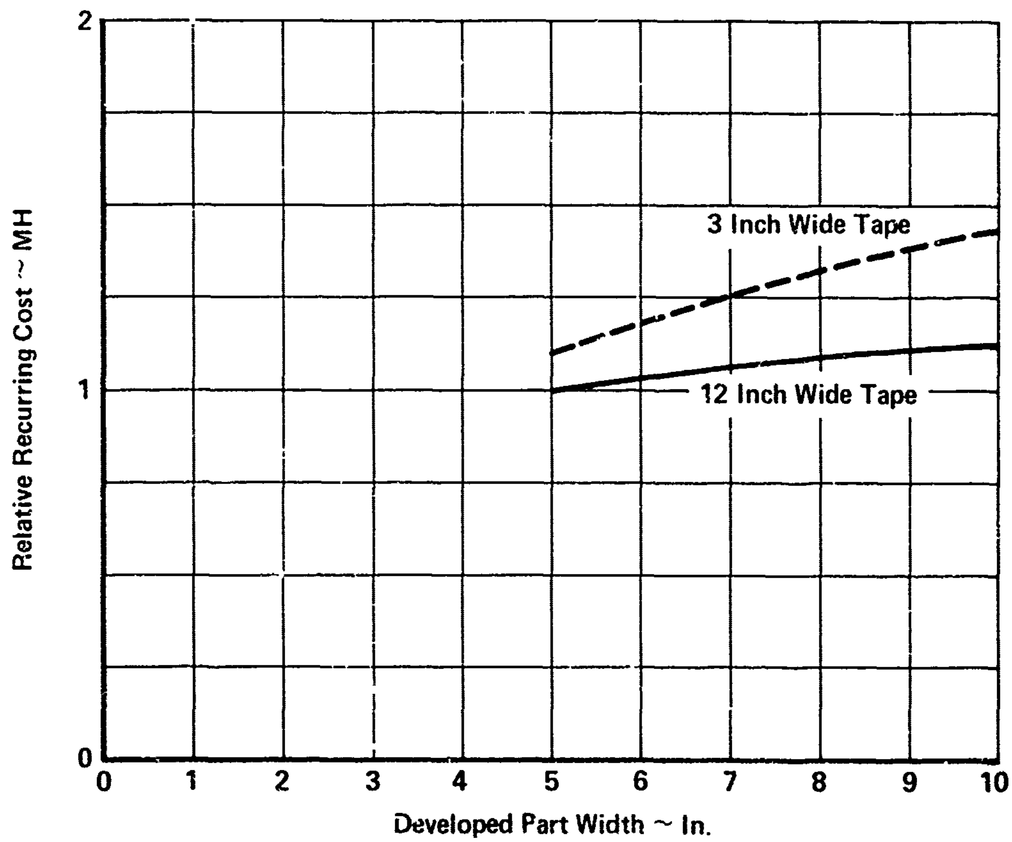
LAMINATE SIZE: 48" x 144"

CDE-G/E-I

EFFECT OF TAPE WIDTH ON COST OF LINEAL SHAPES

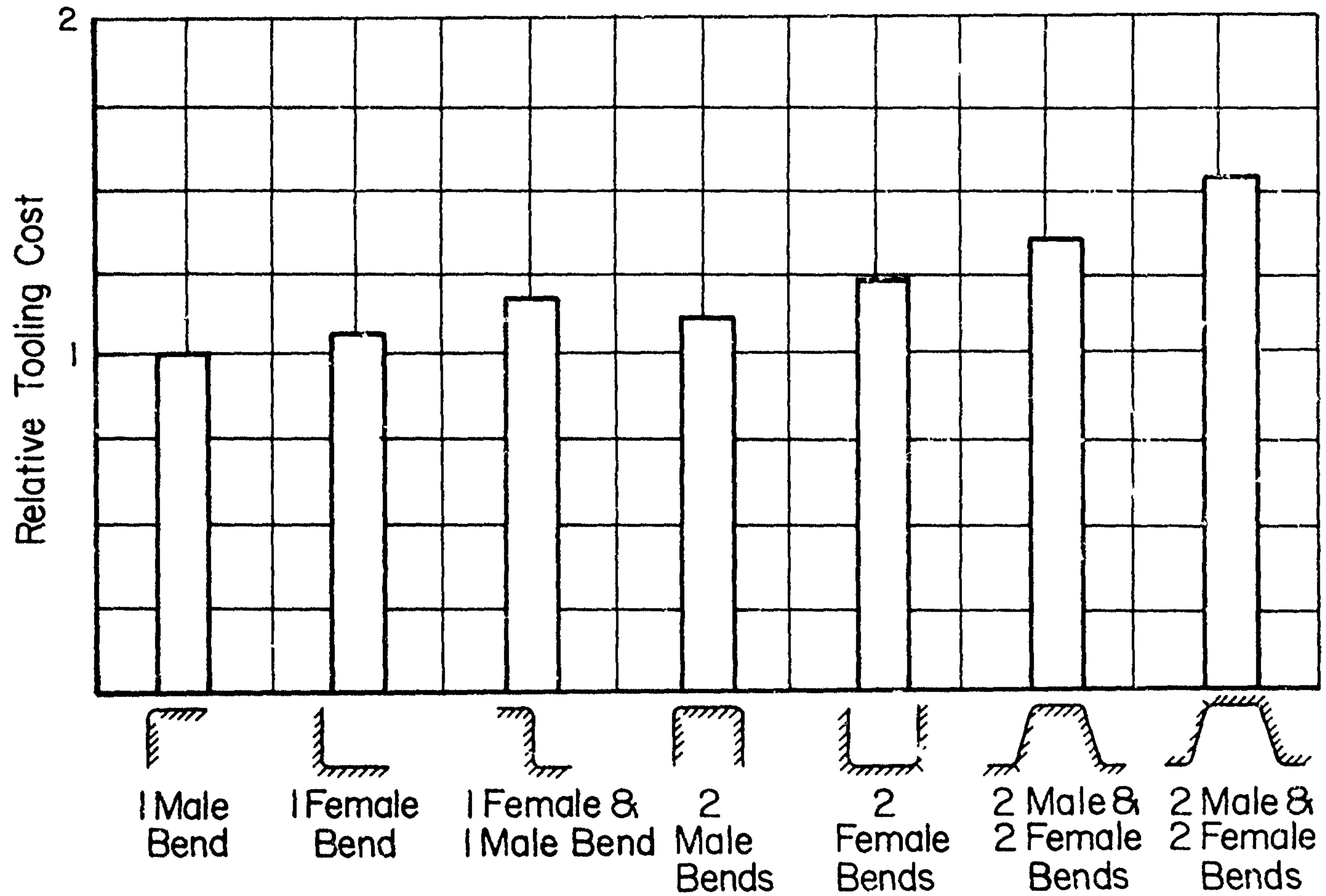
Notes:

- Part Length = 48"
- No Strip Plies



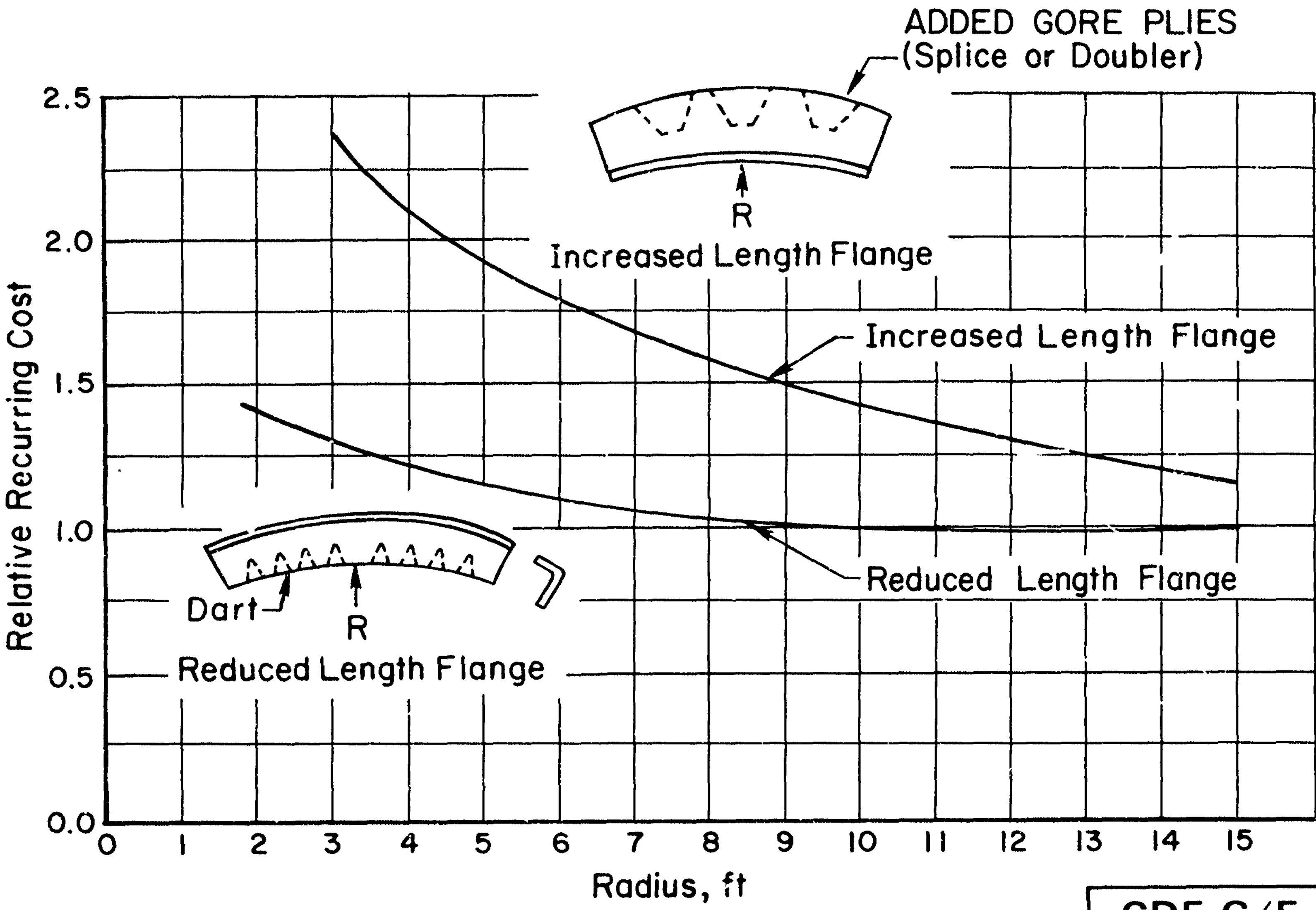
CDE-G/E-II

EFFECT OF {• NUMBER OF BENDS • SHAPE • TOOL TYPE} ON TOOLING COST OF LINEAL SHAPES



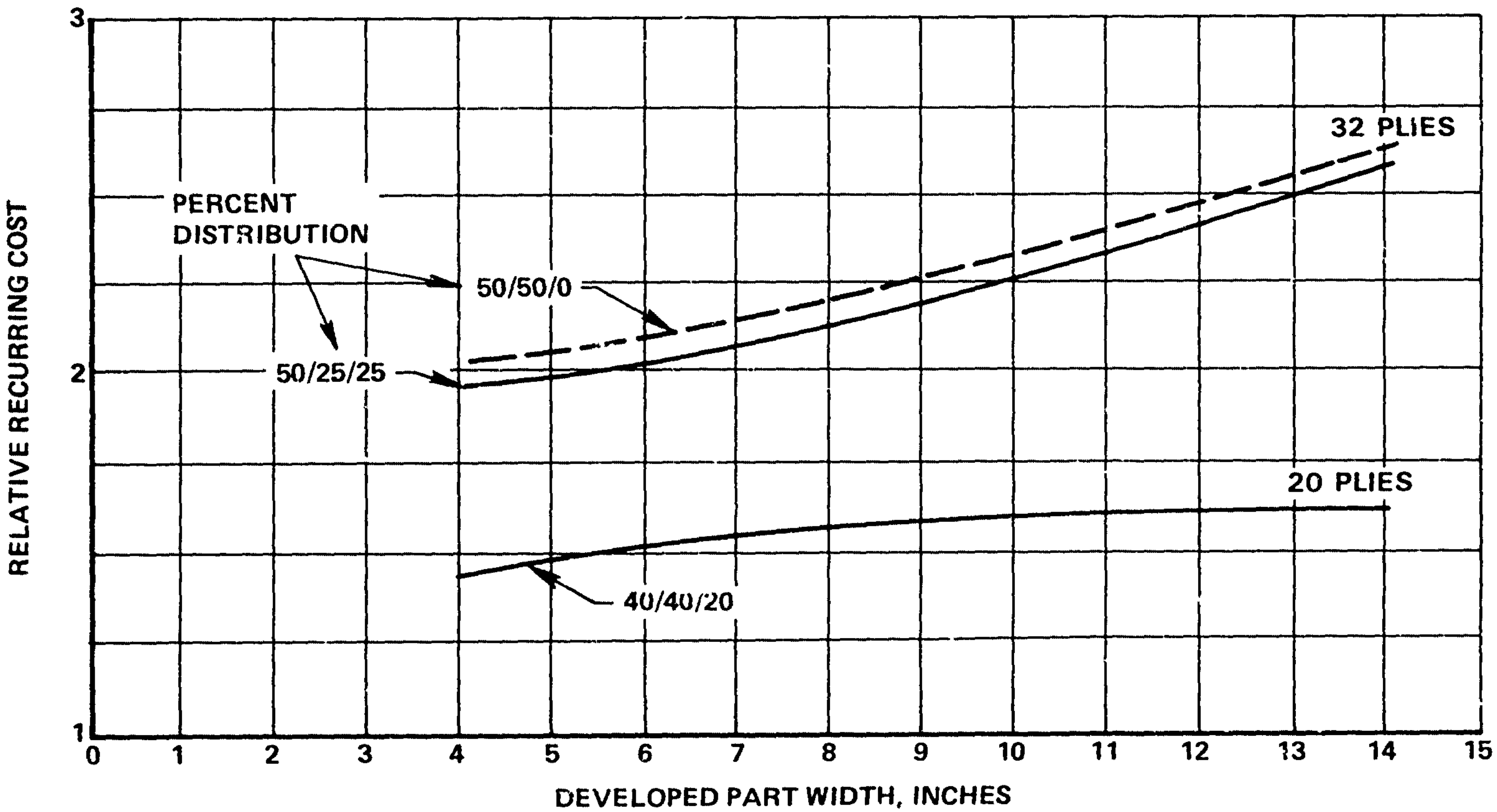
CDE-G/E-III

EFFECT OF RADIUS OF CURVATURE ON RECURRING COST OF LINEAL SHAPES



CDE-G/E-IV

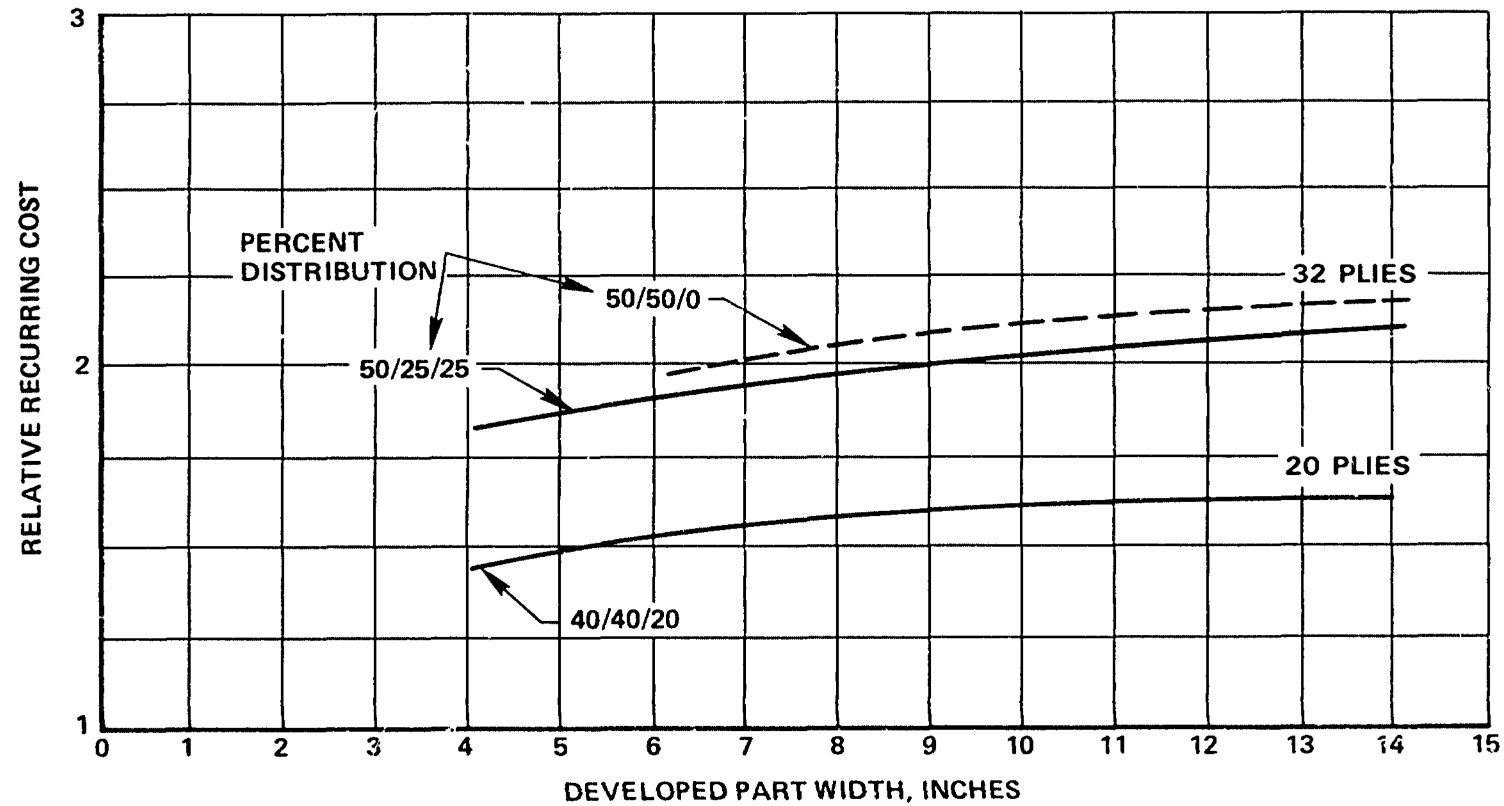
EFFECT OF { ● NO. OF PLIES* ● PLY ORIENTATION ● DEVELOPED WIDTH } ON RECURRING COST OF LINEAL HAT SECTION



*PLY ORIENTATION CODE:
0°/±45°/90°

CDE-G/E-V

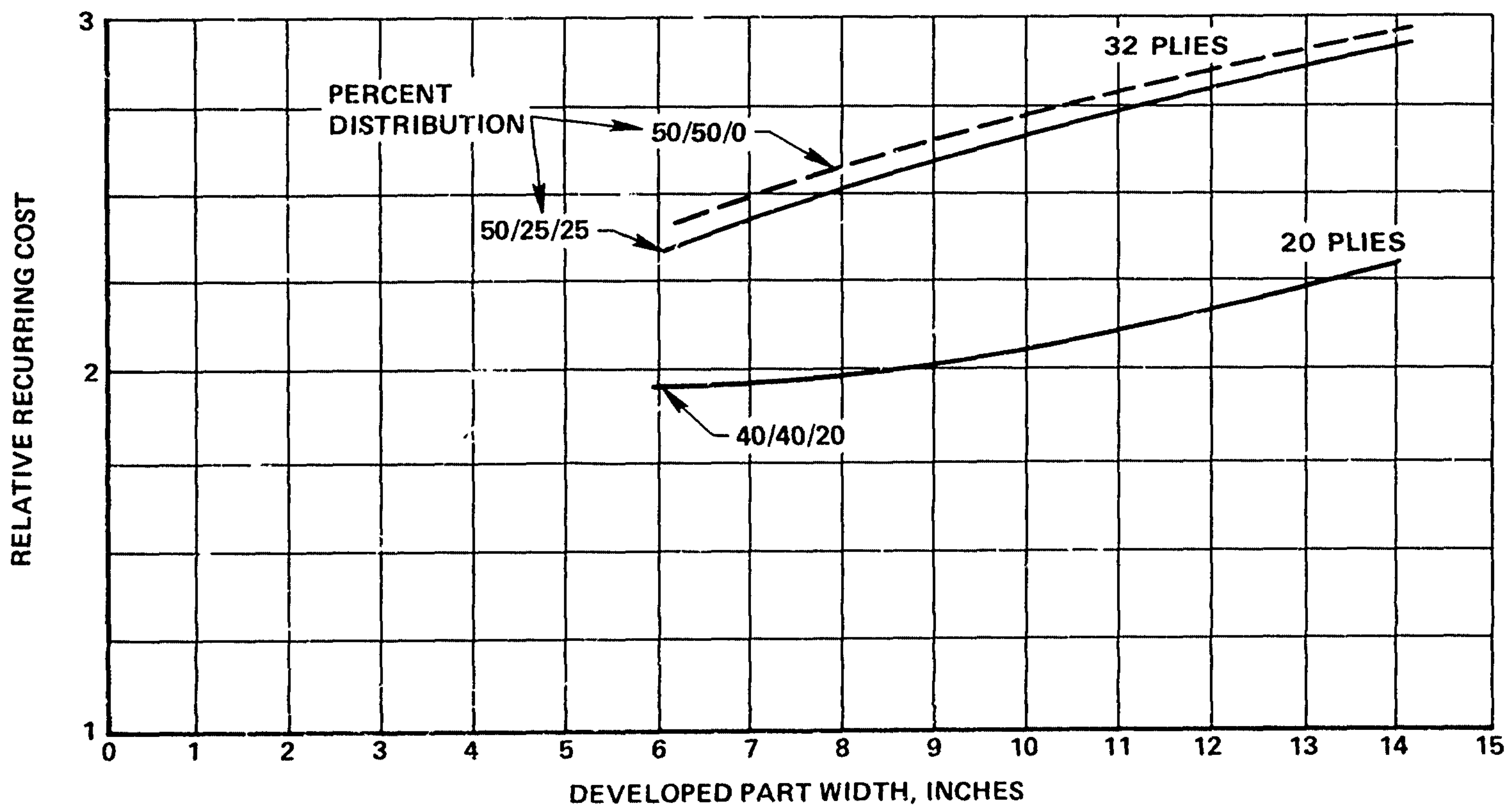
EFFECT OF { ● NO. OF PLIES* ● PLY ORIENTATION ● DEVELOPED WIDTH } ON RECURRING COST OF LINEAL "J" SECTION



*PLY ORIENTATION CODE:
0°/±45°/90°

CDE-G/E-VI

EFFECT OF { • NO. OF PLIES* • PLY ORIENTATION • DEVELOPED WIDTH } ON RECURRING COST OF LINEAL "I" SECTION



*PLY ORIENTATION CODE:
0°/±45°/90°

CDE-G/E-VII

FORMATS FOR

ADVANCED COMPOSITE FABRICATION

COST ESTIMATING DATA (CED)

FORMATS FOR ADVANCED COMPOSITE FABRICATION
COST ESTIMATING DATA (CED)

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as strip-plies, cut-outs, and doublers.

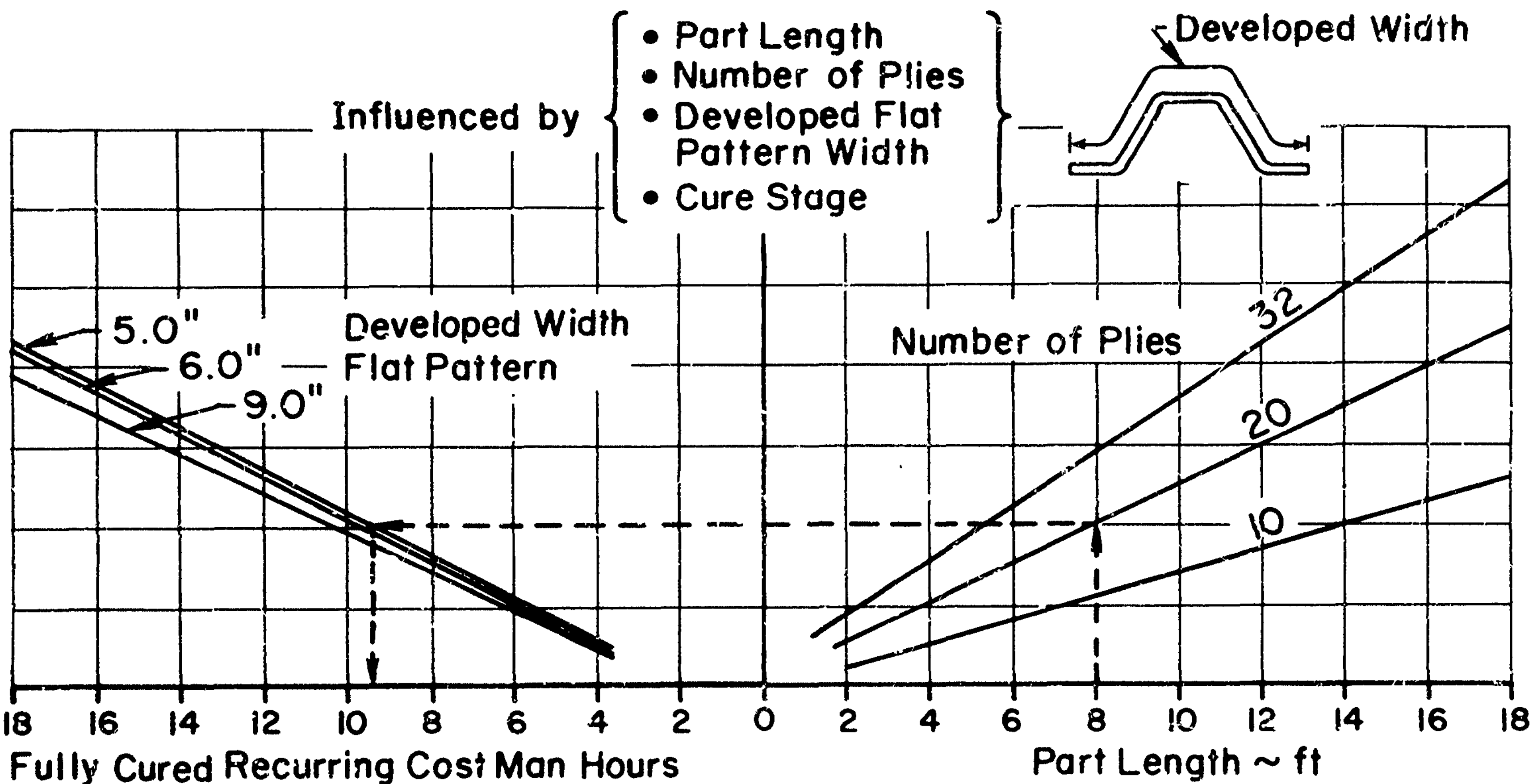
(2) Designer-Influenced Cost Elements (DICE): Includes strip-plies, cut-outs, doublers, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 14. FORMATS FOR COST-ESTIMATING DATA--
ADVANCED COMPOSITES

Format Number	Format Title
CED-G/E-1	Composite Hat Section Recurring Cost/Part
CED-G/E-2	Composite Hat Section Total Non-Recurring Tooling Cost/Part
CED-G/E-3	Composite "J" Section Recurring Cost/Part
CED-G/E-4	Composite "J" Section Total Non-Recurring Tooling Cost/Part
CED-G/E-5	Composite "I" Section Recurring Cost/Part
CED-G/E-6	Composite "I" Section Total Non-Recurring Tooling Cost/Part
CED-G/E-7	Single Curvature Skin Recurring Cost/Part
CED-G/E-8	Single Curvature Skin Non-Recurring Tooling Cost/Part
CED-G/E-9	Assembly Time: Cocured Panel
CED-G/E-10	Assembly and Bagging Time: Cocured Panels
CED-G/E-11	Non-Recurring Tooling Cost: Reusable Rubber Bags
CED-G/E-12	Non-Recurring Tooling Costs: Silastic Plugs

COMPOSITE HAT SECTION RECURRING COST/PART



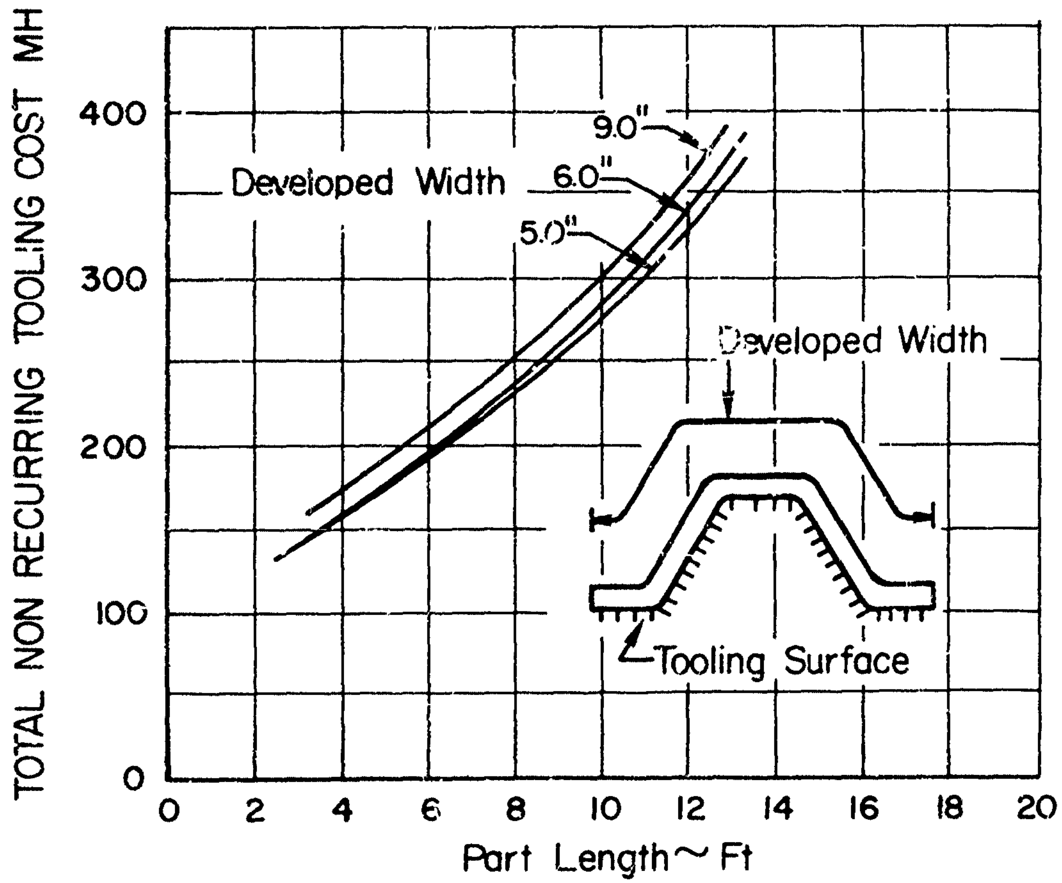
For "B" Staged Recurring Cost, Multiply by 0.84

See Ground Rules for Limitations and Considerations

CED-G/E-1

COMPOSITE HAT SECTION TOTAL NONRECURRING TOOLING COST/PART

Influenced By {• Part Length, • Developed Width}

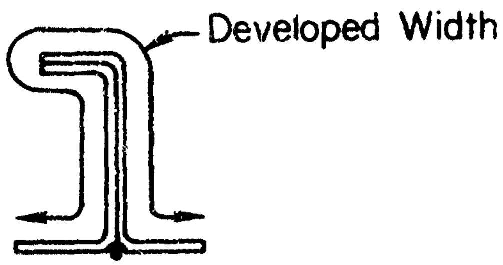


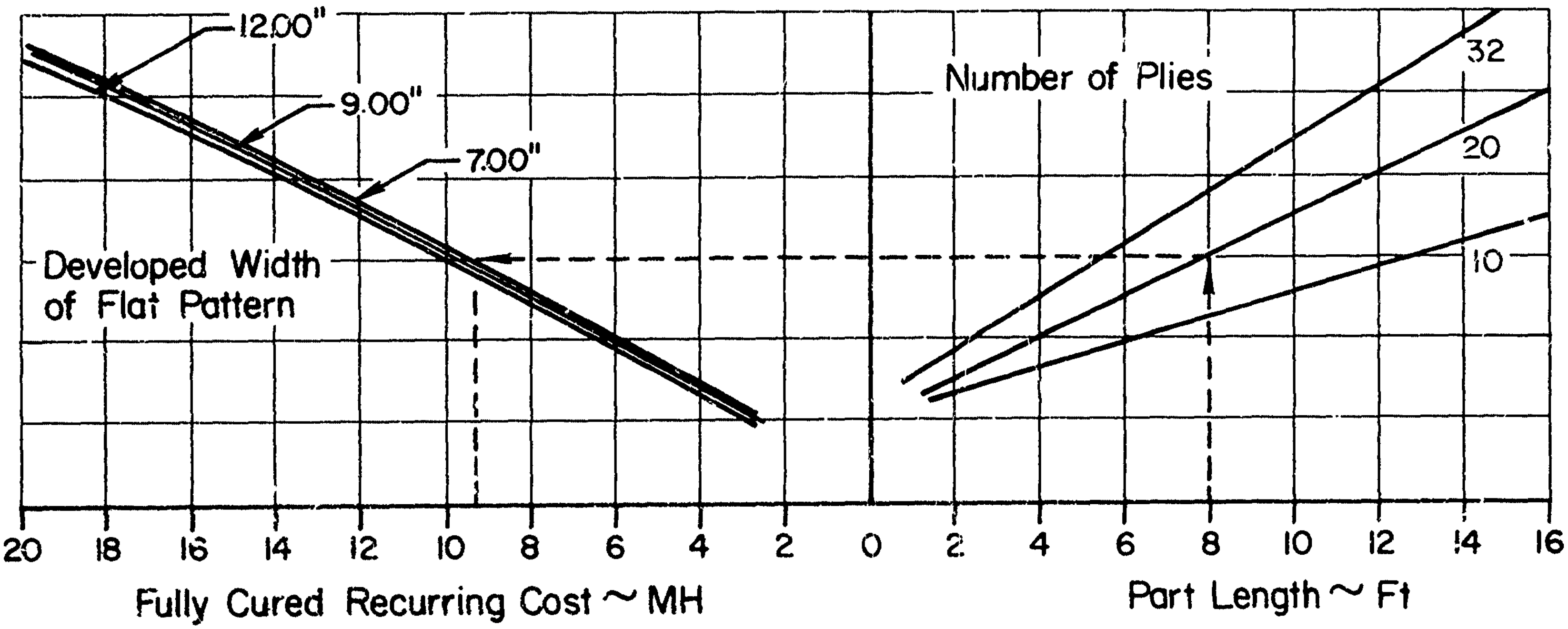
See Ground Rules for Limitations and Considerations

CED-G/E-2

COMPOSITE J SECTION RECURRING COST/PART

Influenced By
- Part Length
- Number of Plies
- Developed Flat Pattern Width
- Cure Stage



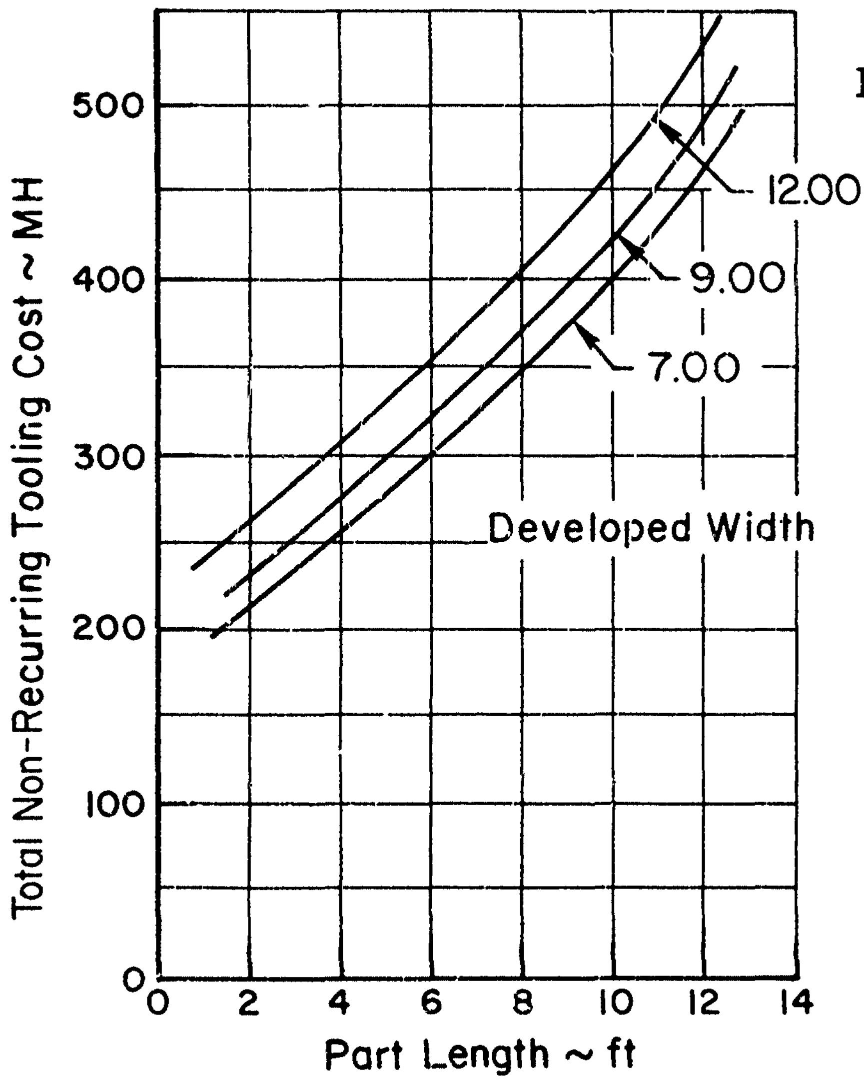


For "B" Stage Recurring Cost, Multiply by 0.84

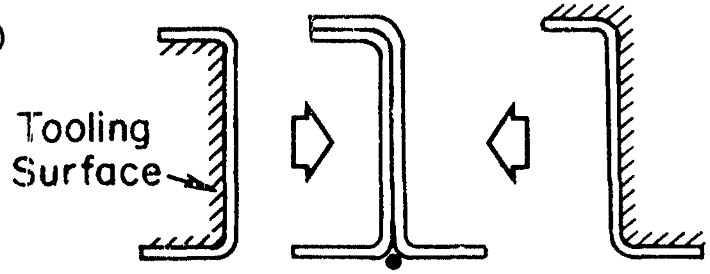
See Ground Rules for Limitations and Considerations

CED-G/E-3

COMPOSITE J SECTION TOTAL NON-RECURRING TOOLING COST/PART



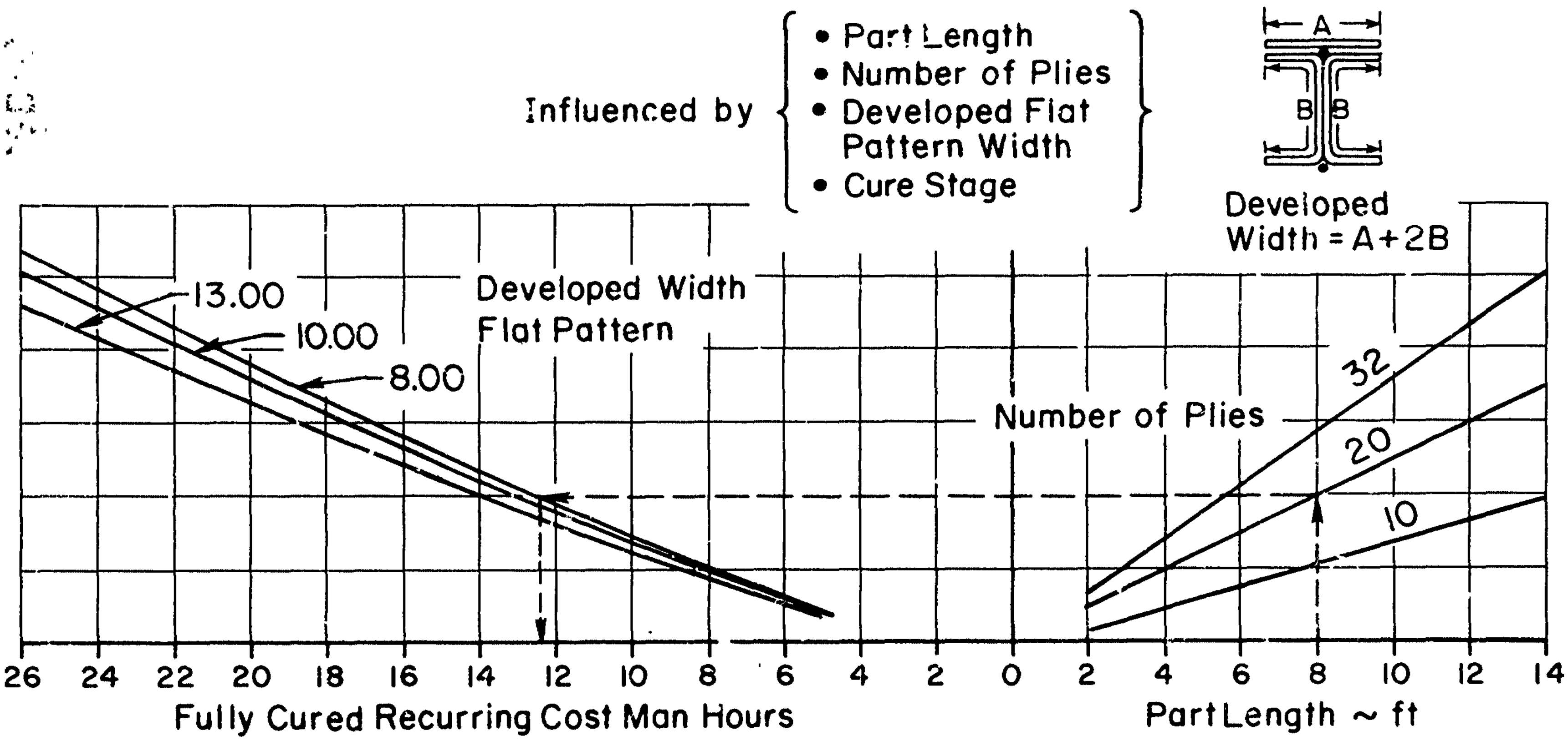
Influenced by {• Part Length • Developed Width}



See Ground Rules for Limitations and Considerations

CED-G/E-4

COMPOSITE I SECTION RECURRING COST/PART



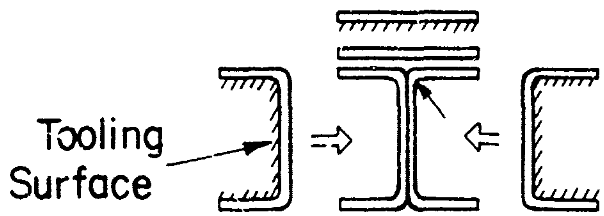
(For "B" Stage Recurring Cost, Multiply by 0.84)

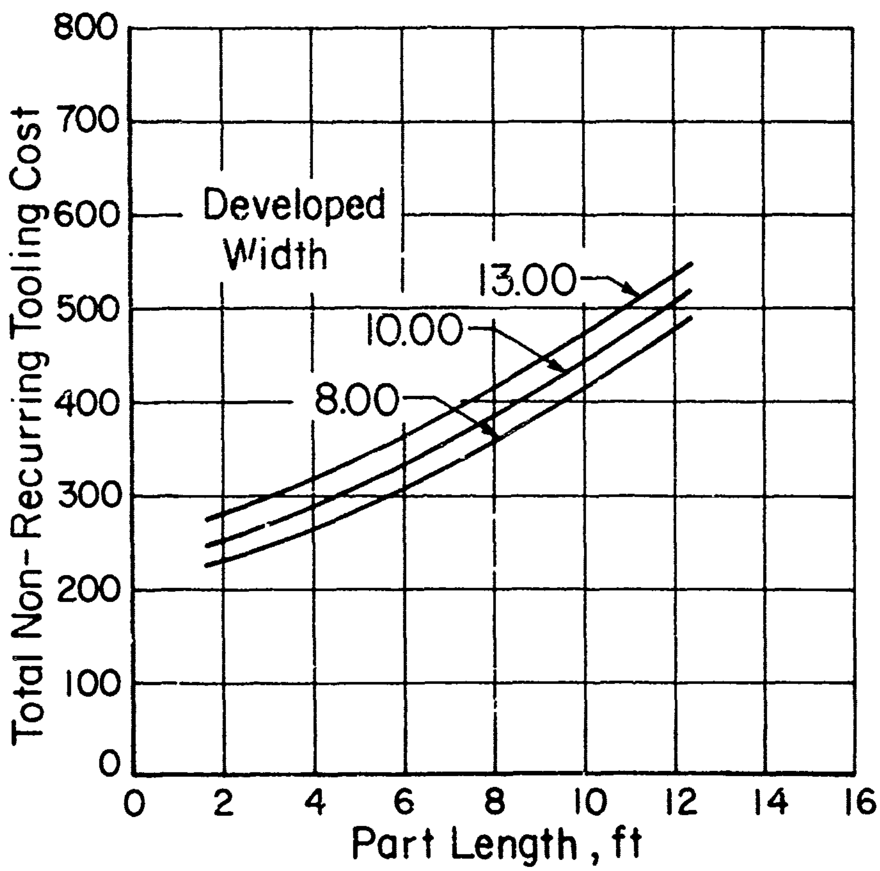
CED-G/E-5

See Ground Rules for Limitations and Considerations

COMPOSITE I SECTION
TOTAL NON-RECURRING TOOLING COST/PART

Influenced By { • Part Length • Developed Width }



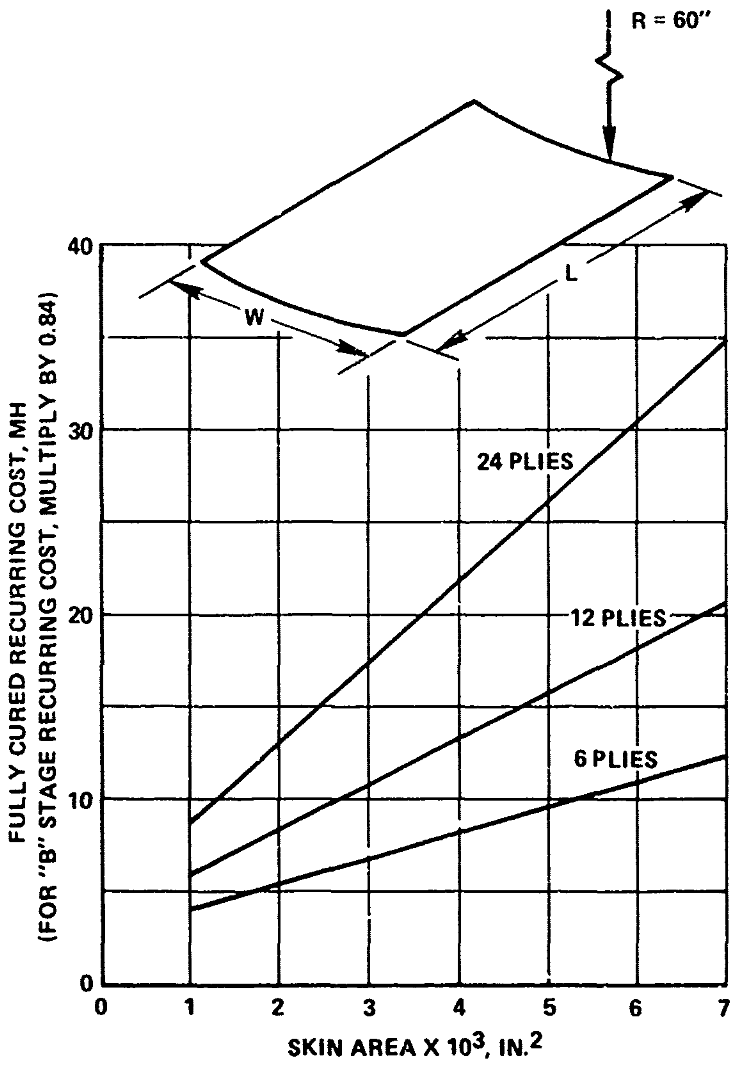


See Ground Rules for Limitations and Considerations

CED-G/E-6

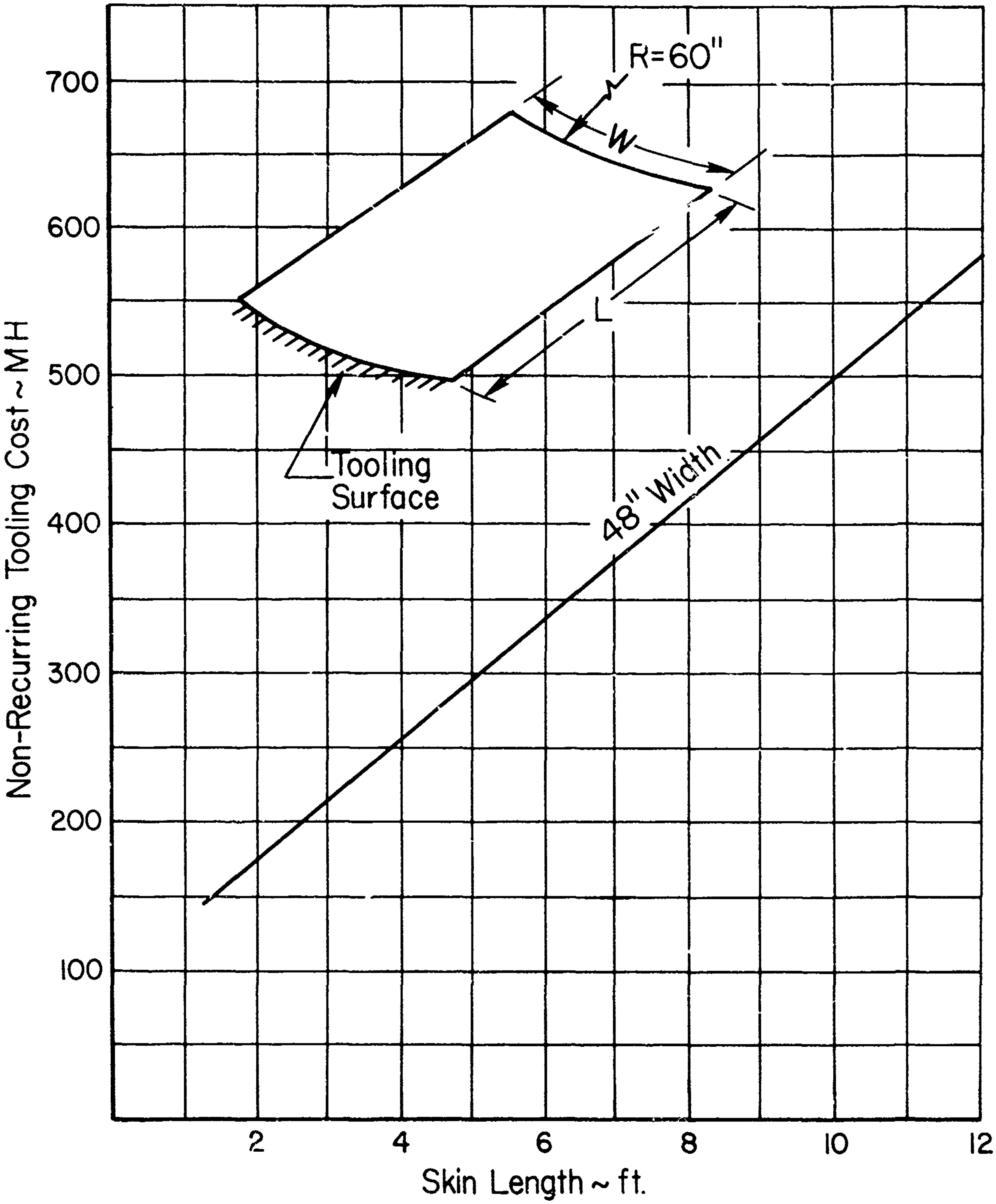
SINGLE CURVATURE SKIN RECURRING COST/PART

INFLUENCED BY
- AREA
- NUMBER OF PLIES
- CURE STAGE



CED-G/E-7

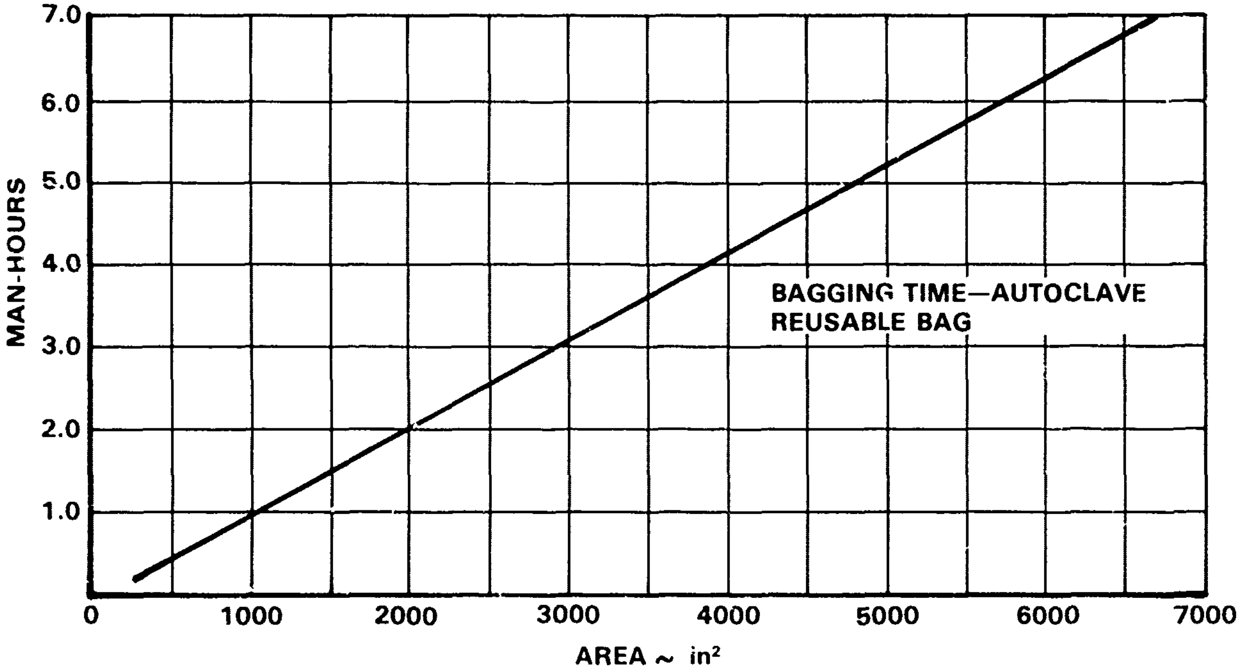
SINGLE CURVATURE SKIN NON-RECURRING TOOLING COST/PART

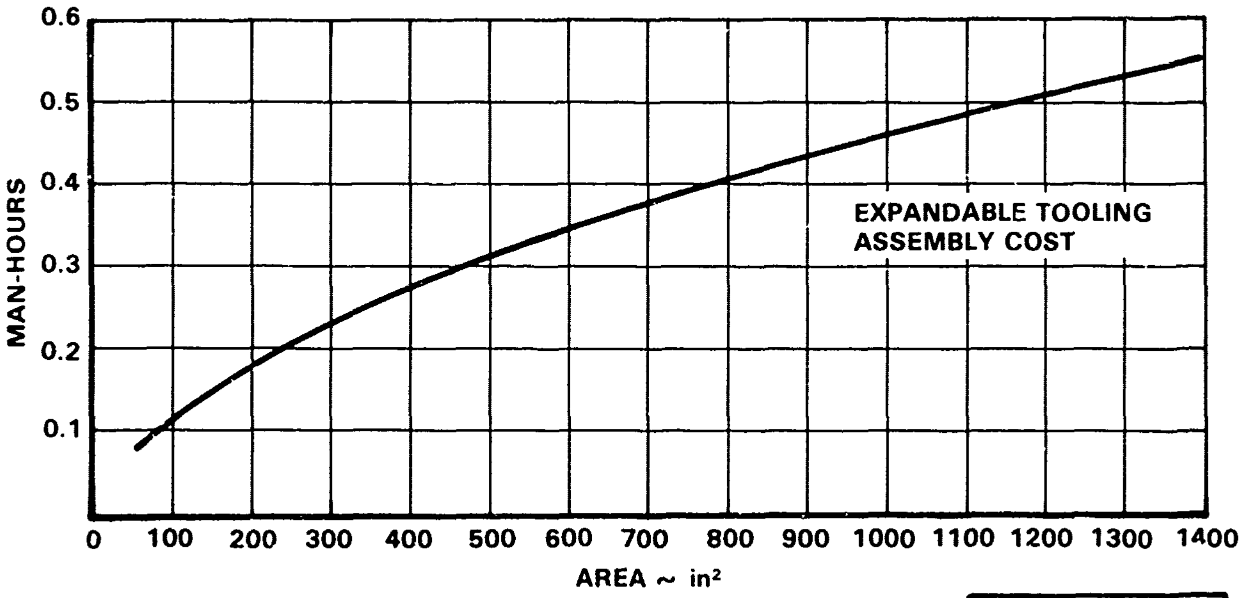


See Ground Rules for Limitations and Considerations

CED-G/E-8

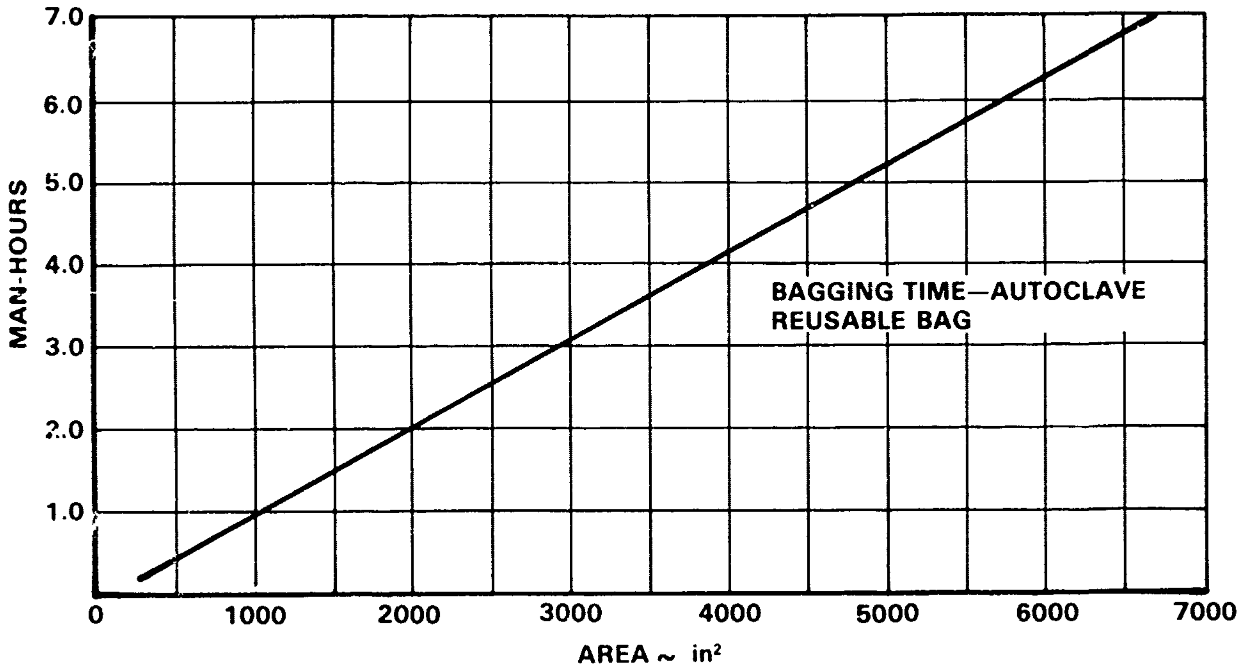
ASSEMBLY TIME—COCURED PANEL

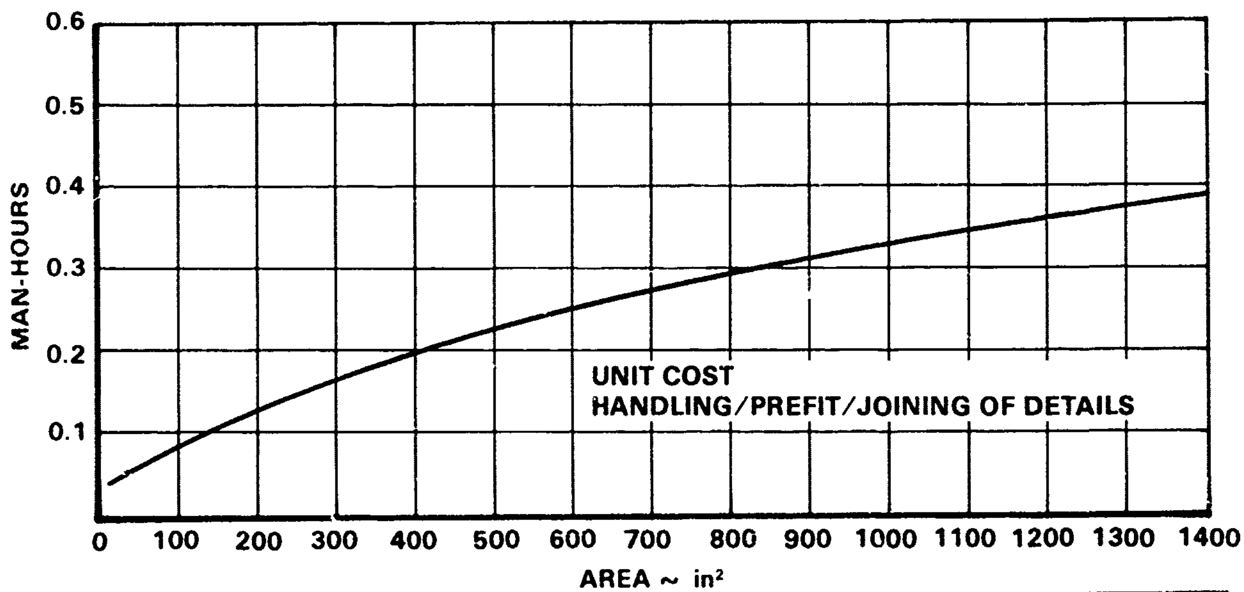




CED-G/E-9

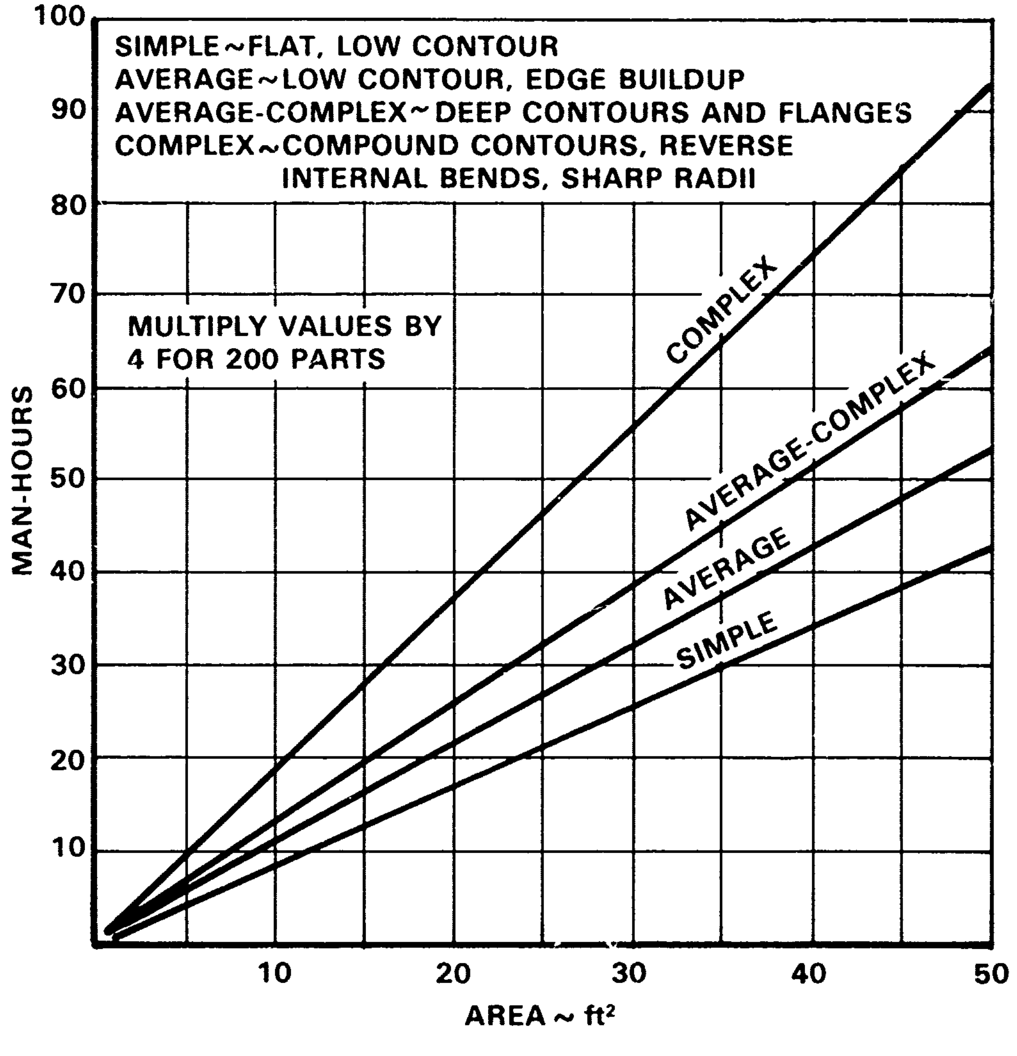
ASSEMBLY AND BAGGING TIME—COCURED PANELS





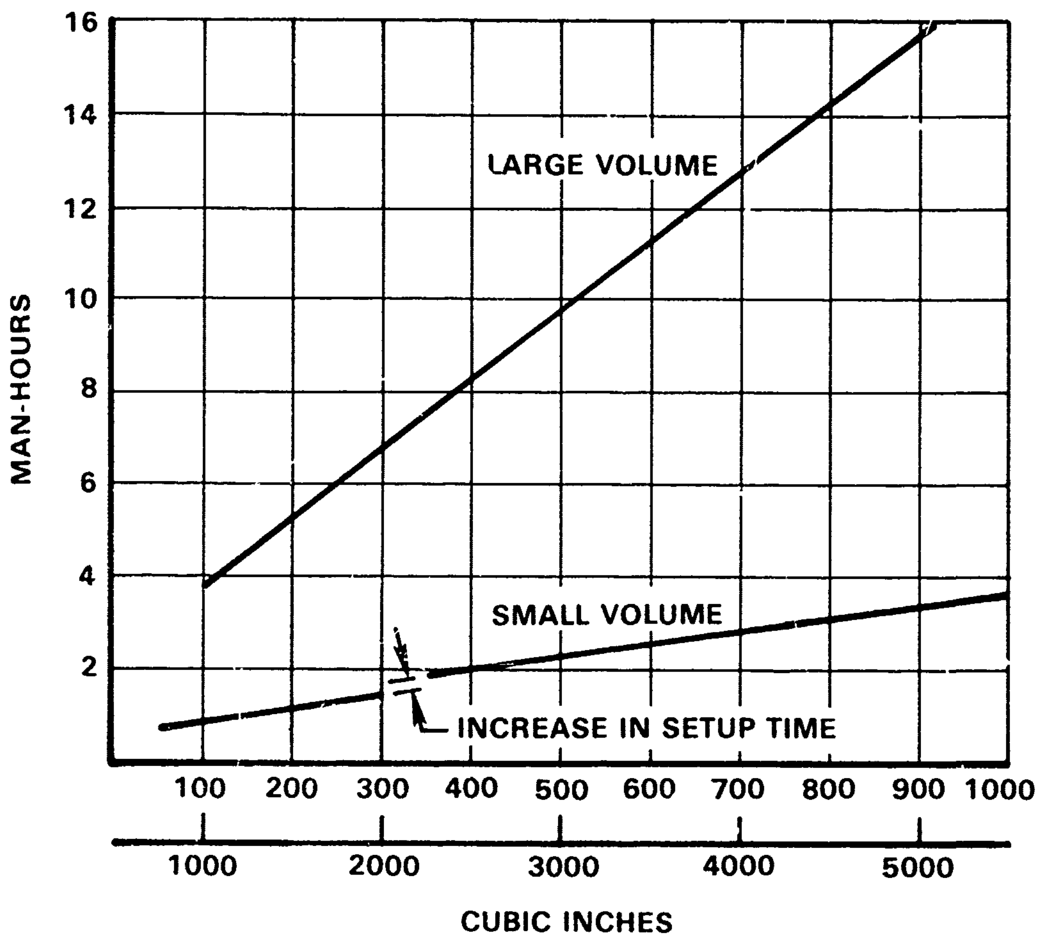
CED-G/E-10

NON-RECURRING TOOLING COST
REUSABLE RUBBER BAGS



CED-G/E-11

NON-RECURRING TOOLING COST
SILASTIC PLUGS



CED-G/E-12

FORMATS FOR

ADVANCED COMPOSITE FABRICATION

DESIGNER-INFLUENCED COST ELEMENTS (DICE)

FORMATS FOR ADVANCED COMPOSITE FABRICATION
DESIGNER-INFLUENCED COST ELEMENTS (DICE)

IMPORTANT DEFINITIONS

(1) Base Part: A detailed part in its simplest form, i.e., without complexities such as strip-plies, cut-outs, and doublers.

(2) Designer-Influenced Cost Elements (DICE): Includes strip-plies, cut-outs, doublers, and special tolerances that add cost to the base part configuration. These additional costs are due to the increased fabrication operations and tooling required over the standard manufacturing method (SMM) for the base part.

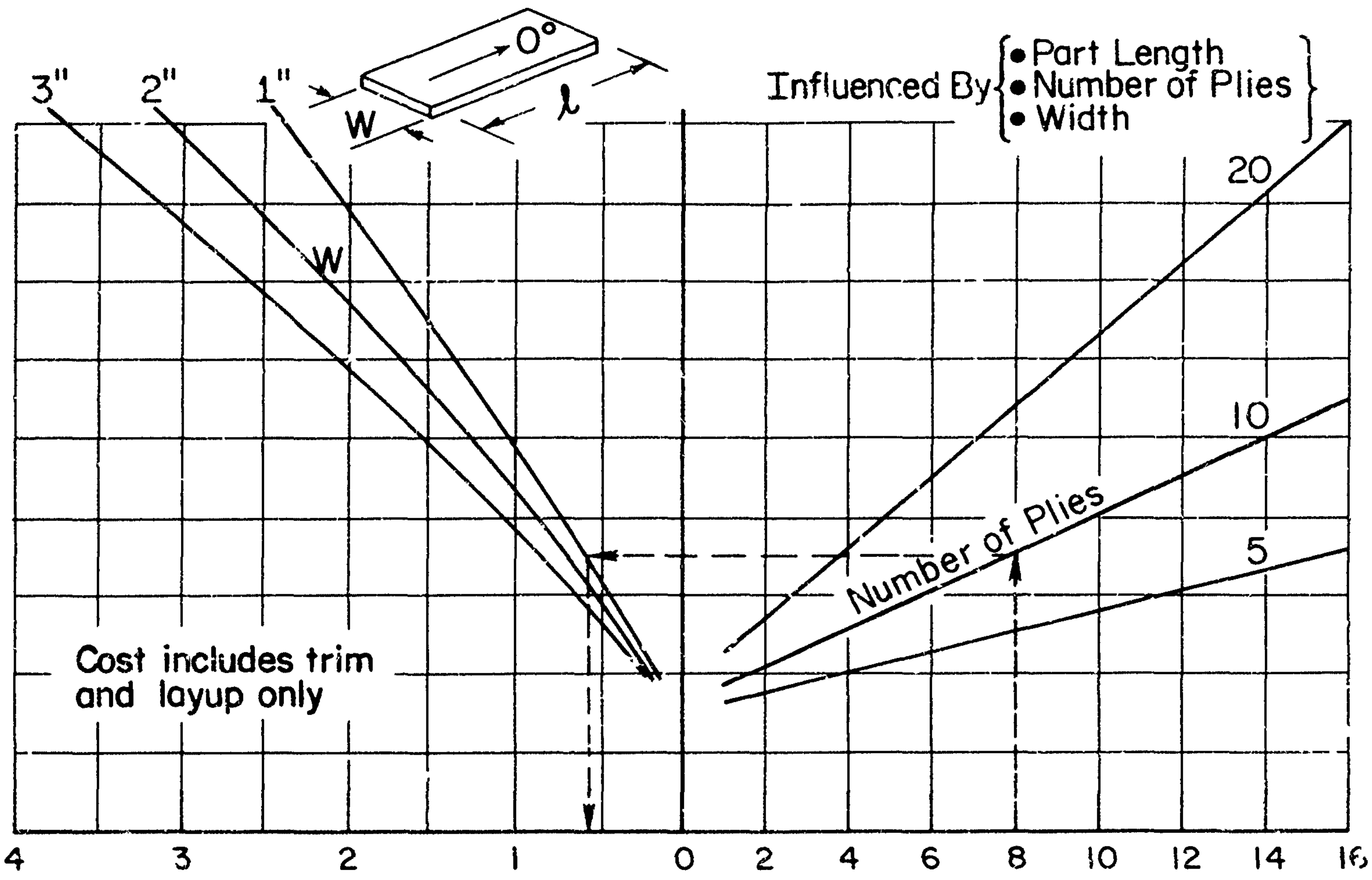
(3) Detailed or Discrete Parts: A distinct airframe structural part which may incorporate complexities, e.g., a base part plus DICE, ready for assembly to perform its required function in the airframe.

TABLE 15. FORMATS FOR DESIGNER-INFLUENCED COST ELEMENTS--ADVANCED COMPOSITES

Format Number	Format Title
DICE-G/E-1	Strip Plies (Flat Parts) for Cocuring: Recurring Cost/Part
DICE-G/E-2	Cutout-Hole Recurring Cost/Detail
DICE-G/E-3	Hole Reinforcing Doubler for Cocuring: Recurring Cost/Detail
DICE-G/E-4	Cutout Reinforcing Doubler for Cocuring: Recurring Cost/Detail
DICE-G/E-5	Clip for Cocuring: Recurring Cost/Part
DICE-G/E-6	Integral Tab: Recurring Cost/Detail

STRIP PLIES (FLAT PARTS) FOR COCURING

RECURRING COST/PART



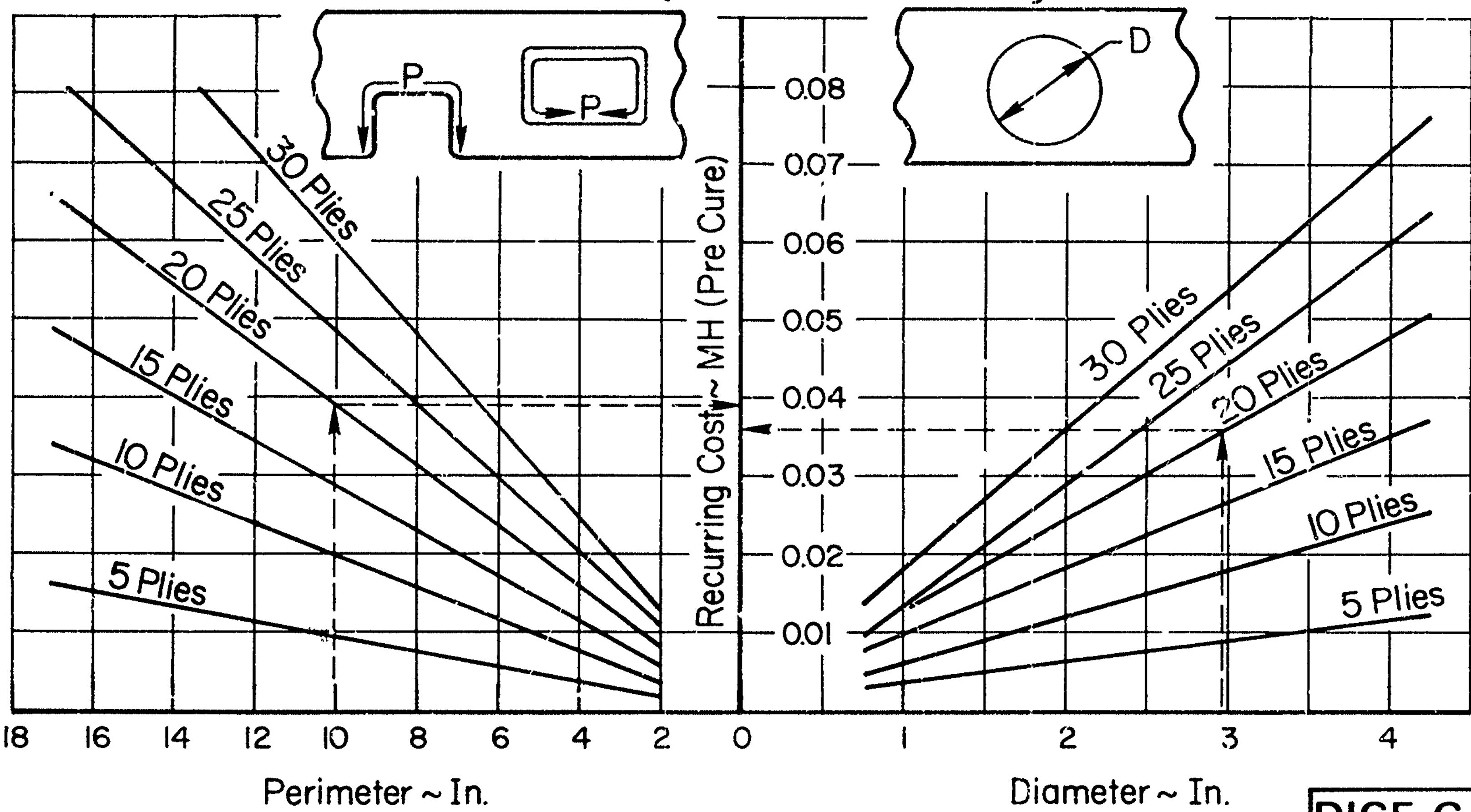
SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-1

CUTOUT-HOLE RECURRING COST/DETAIL

Cost Includes Trim Only

Influenced By { • Hole Shape and Size • Number of Plies }

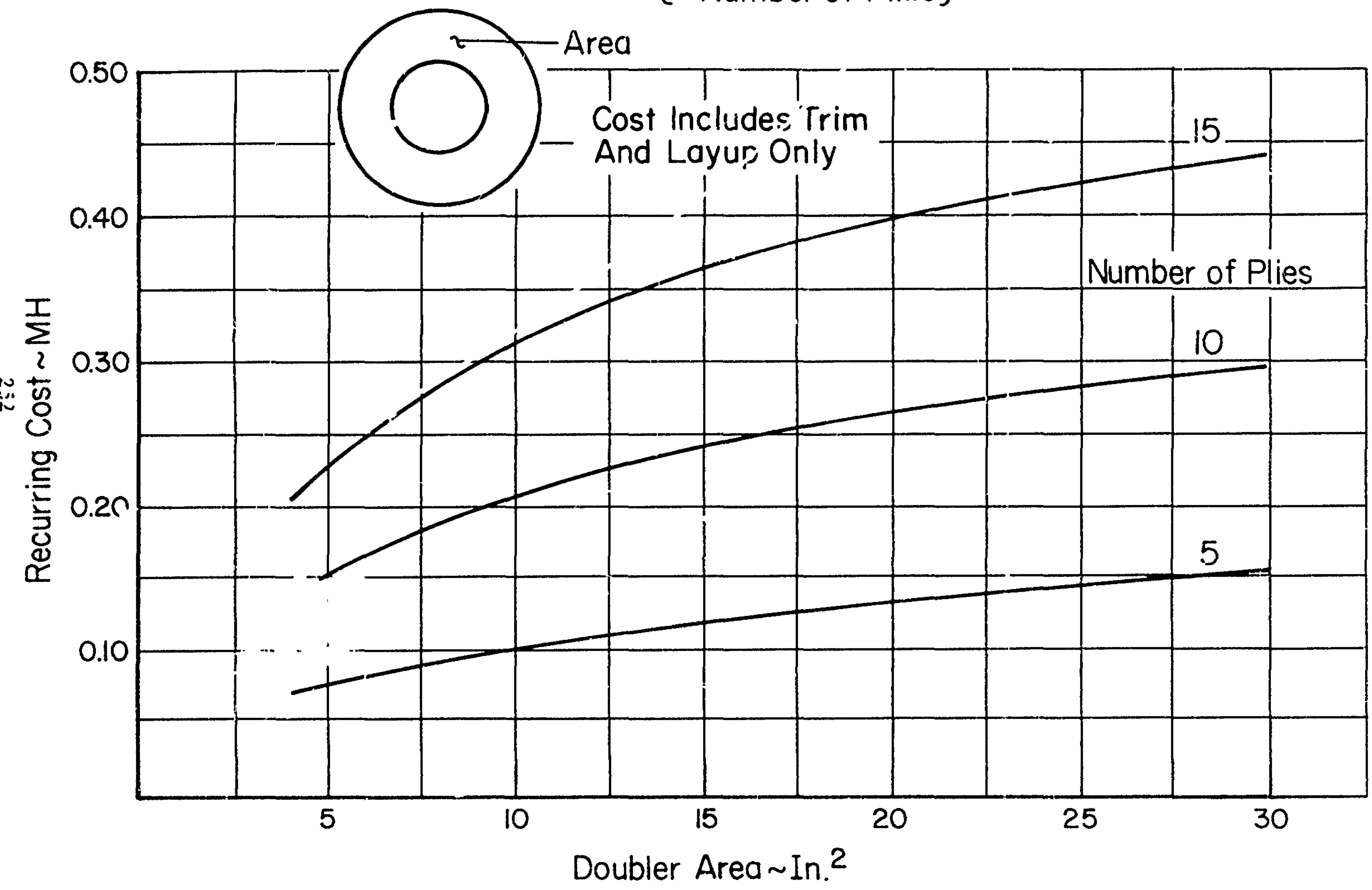


See Ground Rules for Limitations and Considerations

DICE-G/E-2

HOLE REINFORCING DOUBLER FOR COCURING: RECURRING COST/DETAIL

Influenced By { • Area • Number of Plies }

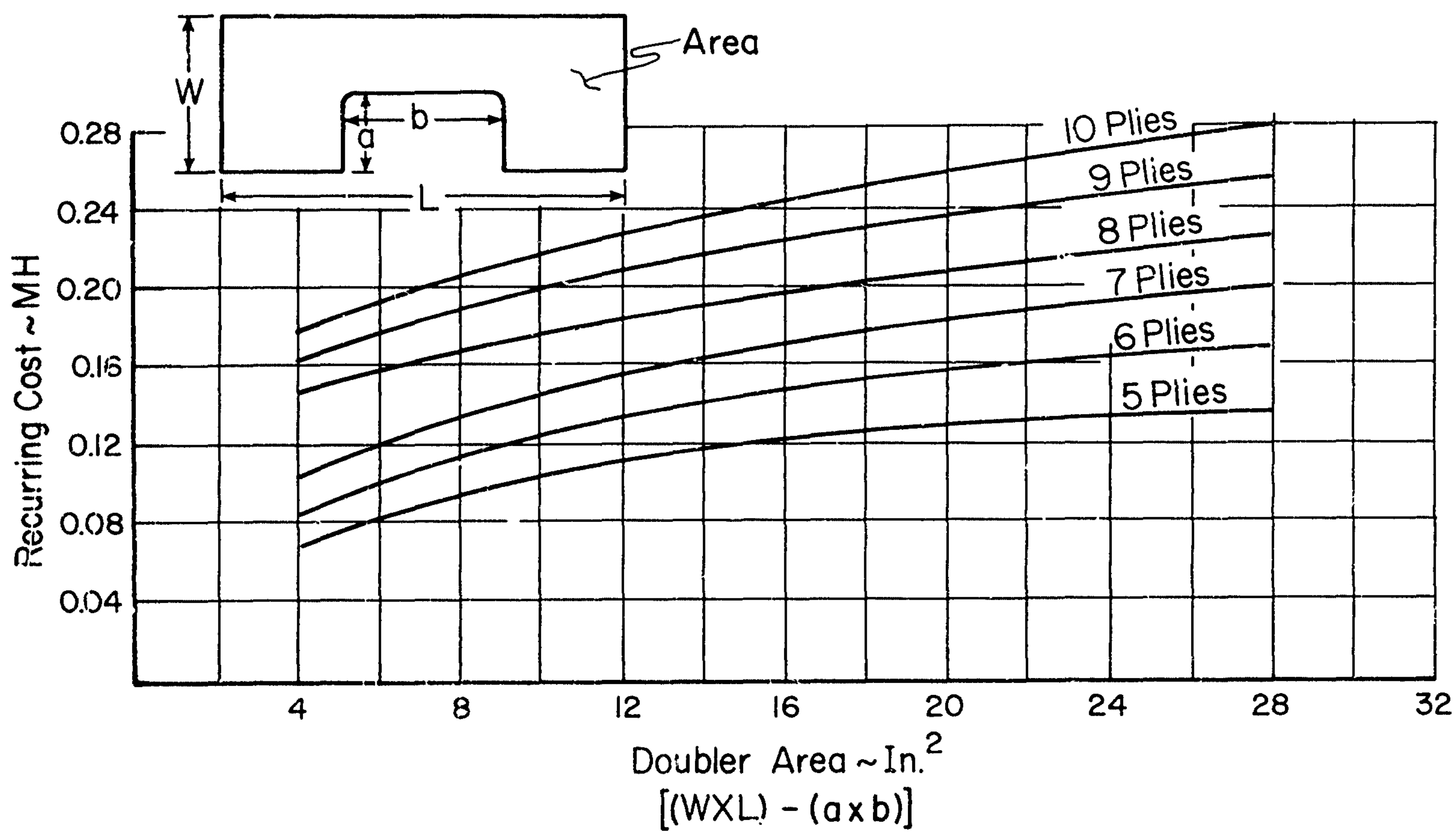


SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-3

CUTOUT REINFORCING DOUBLER FOR COCURING: RECURRING COST/DETAIL

Influenced By { • Area • Number of Plies }

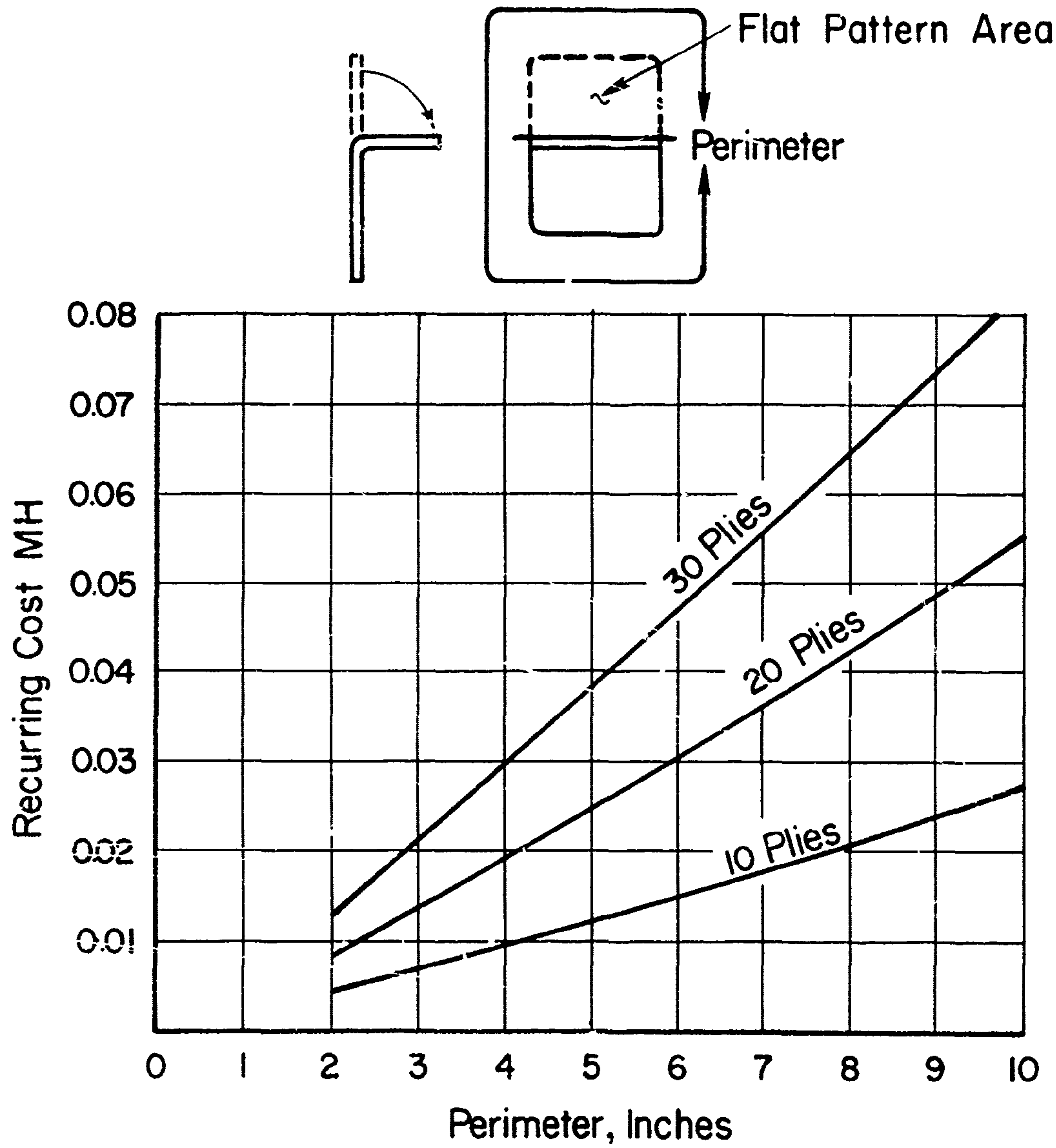


SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-4

CLIP FOR COCURING
RECURRING COST / PART

Influenced By {•Perimeter •Number of Plies}



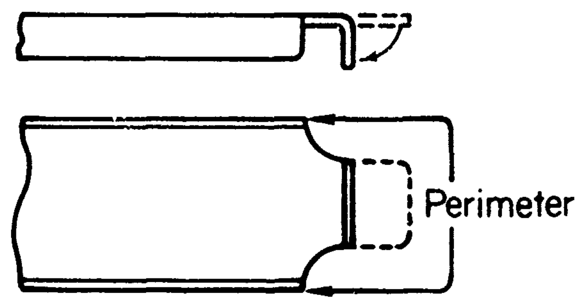
SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

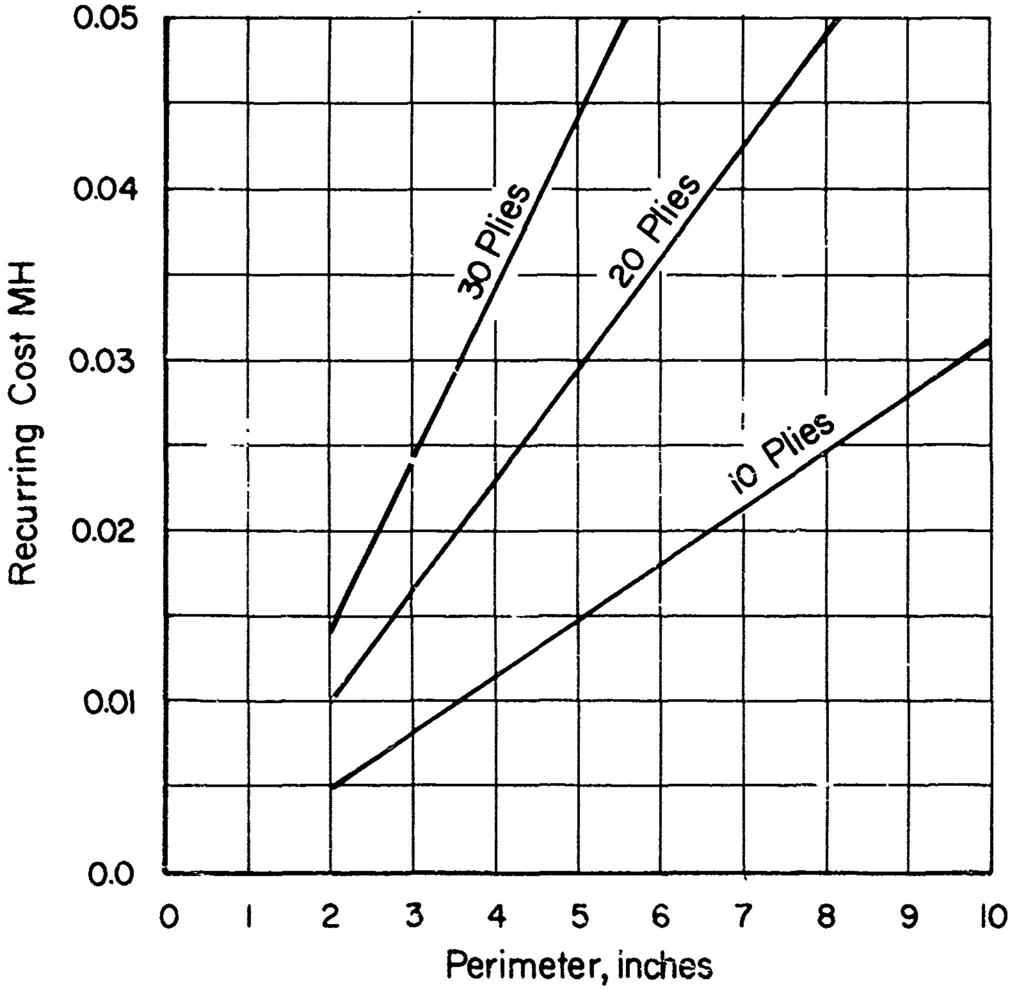
INTEGRAL TAB

RECURRING COST/DETAIL

Influenced By {•Perimeter, •Number of Plies}

Cost Includes Trim Only





SEE GROUND RULES FOR LIMITATIONS AND CONSIDERATIONS

DICE-G/E-6

SECTION X

AIRFRAME TRADE STUDIES

A series of fuselage shear panels were analyzed with regard to weight and cost savings by three team members utilizing the manufacturing man-hour data developed in the three demonstration sections described earlier in this report, i.e., "Sheet-Metal Aerospace Discrete Parts", "Mechanically Fastened Assemblies", and "Advanced Composites Fabrication".

The primary objectives of the fuselage shear panel trade studies were:

- To demonstrate the use of the MC/DG in an industrial environment designing typical airframe structures
- To determine whether the manufacturing cost (man-hour) formats, providing CDE and CED information, meet the format design criteria established for their development
- To determine whether the CDE and CED formats provide the accuracy required by designers in conducting realistic comparisons of airframe configurations utilizing both metallic and composite materials.

Fuselage panel designs were studied in the following structural materials by the design departments in each of the three companies:

- Aluminum alloy--by General Dynamics Corporation, Fort Worth Division
- Titanium alloy--by Lockheed-California Company
- Graphite/epoxy--by Rockwell International, Los Angeles Division.

The fuselage panel trade studies were reviewed by:

- Boeing Commercial Airplane Company
- Northrop Corporation, Aircraft Group.

While each company utilized its own design approaches and procedures in conducting the trade studies, the following trade study flow diagram, Figure 22, provides an overview of the general approach. It will be noted that there are six major steps in conducting the cost/weight trades. These are:

"MANUFACTURING COST/DESIGN GUIDE

TRADE–STUDY FLOW DIAGR

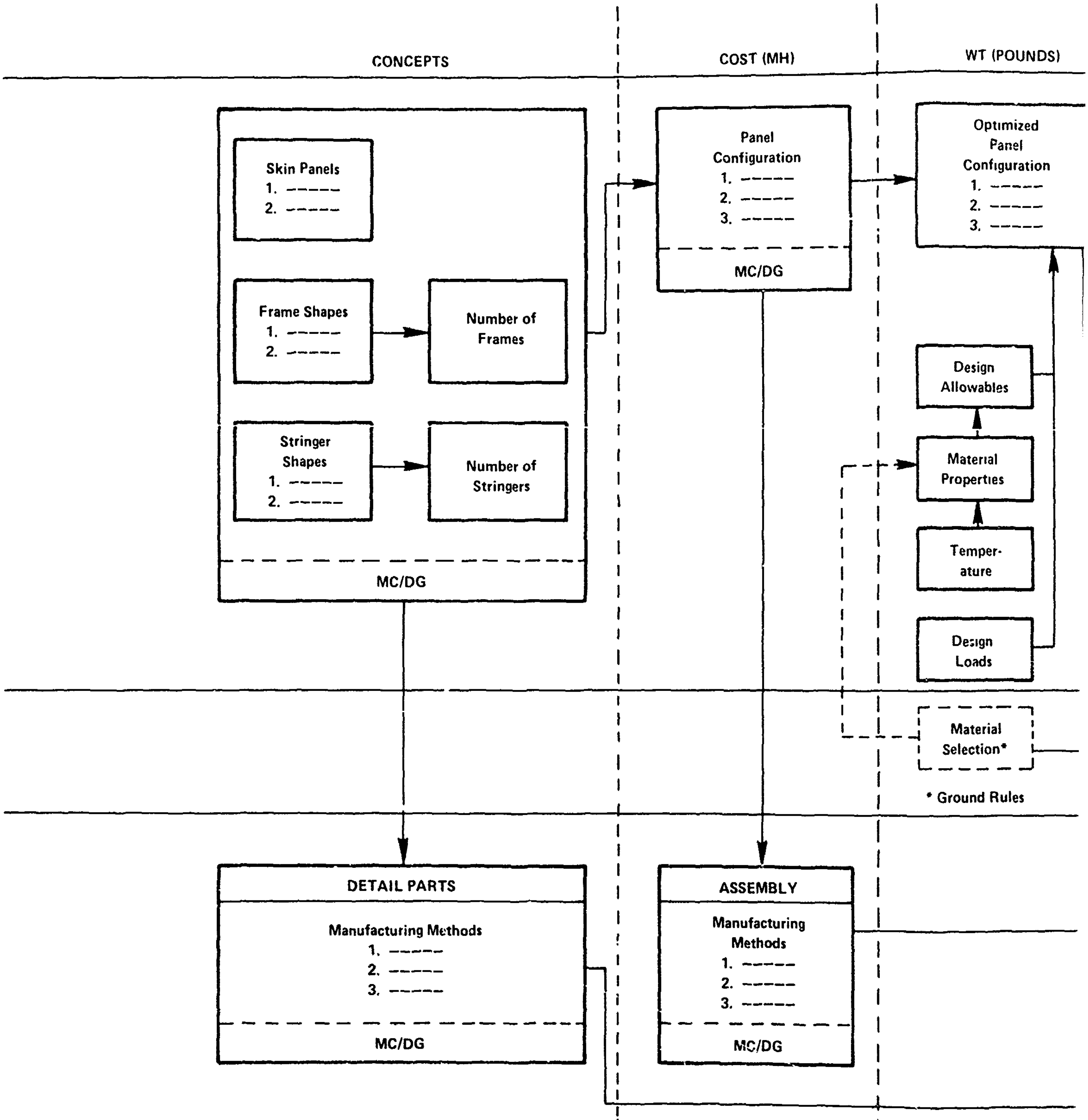


FIGURE 22.

RING COST/DESIGN GUIDE (MC/DG)"

–STUDY FLOW DIAGRAM

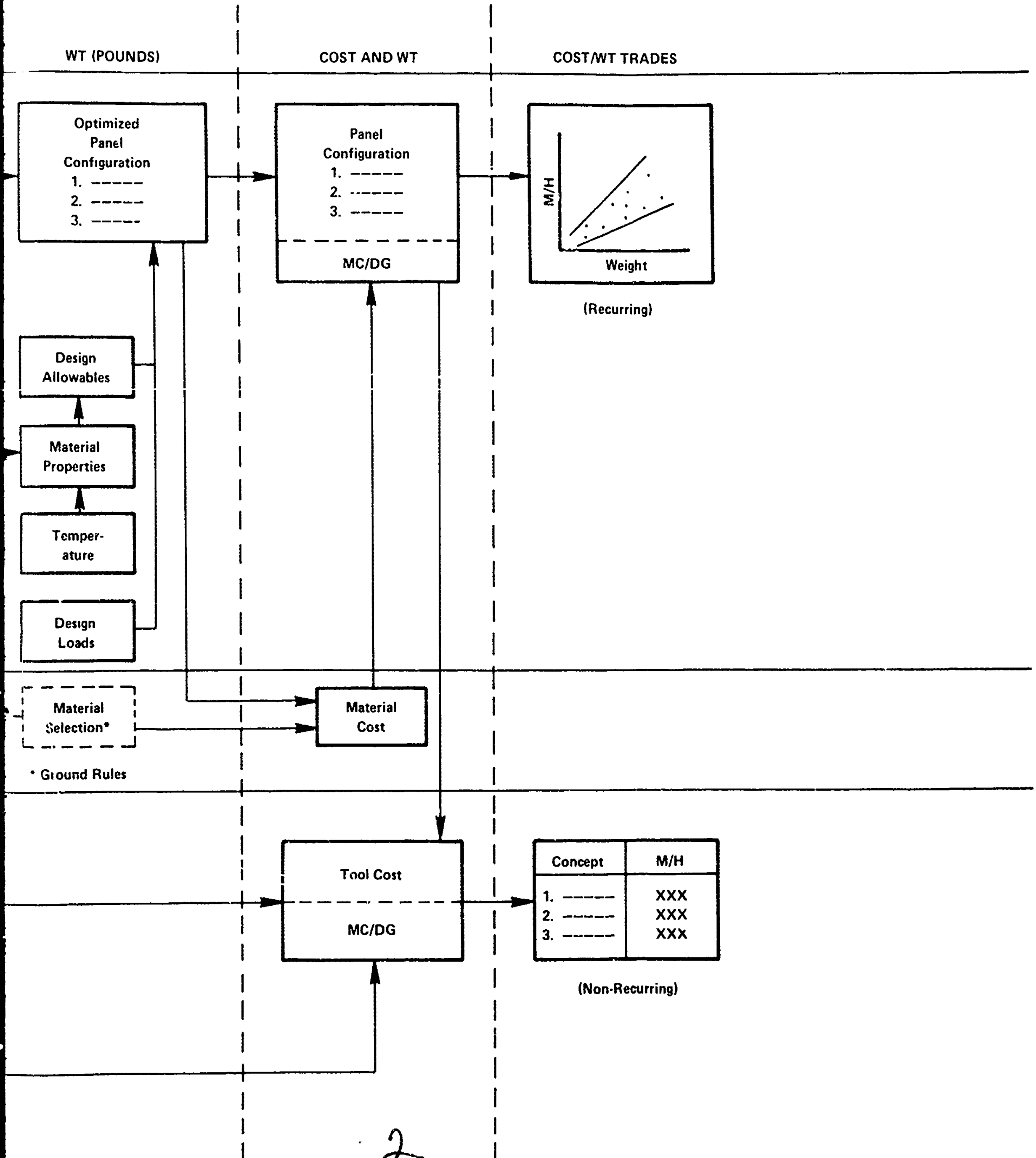


FIGURE 22.

2

(1) Concept Development
- Skin panel sizing
- Frame shape selection
- Number of frames required
- Stringer shapes
- Number of stringers required
- Candidate manufacturing methods to produce each discrete part

(2) Determination of manufacturing cost for each panel configuration

(3) Determination of assembly costs for each configuration

(4) Determination of weight (lbs) for each panel configuration

(5) Determination of total cost, including materials and tooling

(6) Presentation of manufacturing man-hours and structural weight on design charts and tables to facilitate selection of the cost-effective designs.

To determine the total program costs for both discrete parts and assemblies, an MC/DG cost worksheet has been prepared and can be used by industry. This worksheet is shown in Figure 23. A description of the worksheet is given in Table 16.

The three design studies on aluminum, titanium, and advanced composite fuselage panels are summarized in Appendices G, H, and I.

The trade studies provided the opportunity to utilize a good cross-section of designer-oriented formats in each of the MC/DG demonstration sections. The applicable formats are listed in Tables 16 to 19.

The following are the conclusions derived from the trade studies:

- The practicability of the MC/DG demonstrated
- MC/DG provides a quick, efficient designer's tool which:
  - Develops costs to identify lower-cost designs
  - Reduces design time for screening candidate design
  - Improves schedule compliance
- Use of MC/DG in obtaining manufacturing costs and performing simple cost estimates was well demonstrated

PAGE ______ ______

DESIGN CONCEPT		RECURRING COST (RC)									NON-RECURRING COST (NRC)			PROGRAM COST		
		L . LC LR = L$ + M$ = RC . P/AC . DQ = PRC									NRC . LR = PNRC			9 + 12 ÷ DQ = COST/AC		
PART NO.	DESCRIPTION	LABOR MC/DG MH/PT (1)	LC FACTOR (2)	LABOR RATE $/MH (3)	LABOR RC $/PT (4)	MAT'L $/PT (5)	REC. COST/ PT. $ (6)	PARTS PER AC (7)	DES. QTY. (8)	PROG. RC $ (9)	NRC MC/DG MH (10)	LABOR RATE $/MH (11)	PROG. NRC $ (12)	PROG. COST $ (13)	DES. QTY. (14)	COST/ AC $ (15)
	TOTALS															

REMARKS ______________________________

BY. ______________

DATE. ______________

FIGURE 23. MC/DG COST WORKSHEET

TABLE 16. DESCRIPTION OF MC/DG COST WORKSHEET FOR DESIGNERS

Part No.: Identification, if available

Description: Brief Description--Stiffener, Zee, J section, etc.

Column	Input	Procedure
1	Labor	From CED section determine man-hours per part at 200 units
2	Learning curve (LC) factor	Based upon learning curve percentage and design quantity. Factor provided by user company.
3	Labor rate	Current manufacturing labor rate including direct labor fringe benefits and overhead charges
4	Labor recurring costs (RC)	Product of Column 1 times Column 2 times Column 3
5	Material cost	Based upon furnished data in company utilizing MC/DG; enter material cost per part in dollars
6	Recurring cost (RC) per part	Total of Columns 4 and 5
7	Parts per aircraft	Number of identical parts per aircraft
8	Design quantity	Number of aircraft in buy considered
9	Program recurring cost (RC)	Product of Column 6 times Column 7 times Column 8
10	Non-recurring tooling cost (NRTC)	From MC/DG, enter total NRTC in man-hours
11	Labor rate	Same as Column 3
12	Program non-recurring tooling costs (NRTC)	Column 10 times Column 11
13	Program cost	Sum of Column 9 and Column 12
14	Design quantity	Same as Column 8
15	Cost per aircraft	Column 13 divided by Column 14

TABLE 17. ALUMINUM FUSELAGE PANEL TRADE STUDY

Formats Utilized

Concept Number	Cost Item	MC/DG Format Number
Base	Skin	CED-A-20
IA	Skin	CED-A-20
	Frames	CED-A-8
	Joggles	DICE-2
	Assembly	CED-MFA-1 and CED-MFA-2
IB	Skin	CED-A-20
	Frames	CED-A-8
	Joggles	DICE-2
	Cut-outs	DICE-1
	Assembly	CED-MFA-1 and CED-MFA-3
IIA	Skin	CED-A-20
	Frames	CED-A-8
	Stringer	CED-A-4
	Clips	CED-A-1
	Joggles	DICE-2
	Trim After Forming	DICE-5
	Assembly	CED-MFA-1 and CED-MFA-3
IIB	Skin	CED-A-21
	Frames	CED-A-9
	Stringers	CED-A-6
	Clips	CED-A-1
	Joggles	DICE-2
	Trim After Forming	DICE-5
	Assembly	CED-MFA-1 and CED-MFA-3
IIIA	Skin	CED-A-20
	Stringers	CED-A-4
	Joggles	DICE-2
	Assembly	CED-MFA-1 and CED-MFA-3

TABLE 18. TITANIUM FUSELAGE PANEL TRADE STUDY

Formats Utilized

Concept Number	Cost Item	MC/DG Format Number
I	Skin	CED-T-7
	Stringers	CED-T-5
	Frames	CED-T-6
	Frame Angles	CED-T-2
	Clips	CED-T-1
	Trim After Forming	DICE-13
	Assembly	CED-MFA-2 and CED-MFA-3
II	Skin	CED-T-7
	Stringers	CED-T-5
	Frames	CED-T-6
	Frame Angles	CED-T-2
	Clips	CED-T-1
	Trim After Forming	DICE-13
	Assembly	CED-MFA-2 and CED-MFA-3
III	Skin	CED-T-7
	Stringers*	Future MC/DG Requirement
	Frames	CED-T-6
	Frame Angles	CED-T-2
	Clips	CED-T-1
	Trim After Forming	DICE-13
	Assembly	CED-MFA-2 and CED-MFA-3
IV	Skin	CED-T-7
	Stringers*	Future MC/DG Requirement
	Frames	CED-T-6
	Frame Angles	CED-T-2
	Clips	CED-T-1
	Trim After Forming	DICE-13
	Assembly	CED-MFA-2 and CED-MFA-3
V	Skin	CED-T-7
	Stringers*	Future MC/DG Requirement
	Frames	CED-T-6
	Frame Angles	CED-T-2
	Clips	CED-T-1
	Trim After Forming	DICE-13
	Assembly	CED-MFA-2 and CED-MFA-3

* Manufacturing man-hours determined by conventional cost-estimating procedures.

TABLE 18. (Continued)

Concept Number	Cost Item	MC/DG Format Number
VI	Skin	CED-T-7
	Stringers*	Future MC/DG Requirement
	Frames	CED-T-6
	Frame Angles	CED-T-2
	Clips	CED-T-1
	Trim After Forming	DICE-13
	Assembly	CED-MFA-2 and CED-MFA-3
VII	Skin	CED-T-7
	Frame	CED-T-6
	Trim After Forming	DICE-13
	Assembly	CED-MFA-2 and CED-MFA-3

* Manufacturing man-hours determined by conventional cost-estimating procedures.

TABLE 19. ADVANCED COMPOSITES TRADE STUDY

Formats Utilized

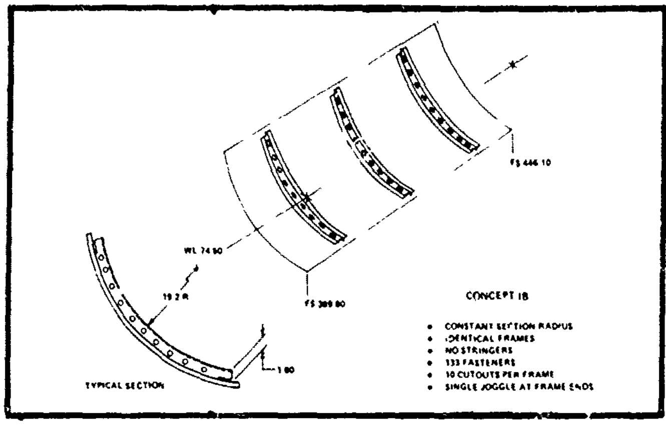
Concept	Cost Item	Format Number
Lightweight/High Complexity Mechanically-Fastened	Skin	CED-G/E-7 and CED-G/E-8
	Hat Stringers	CED-G/E-1 and CED-G/E-2
	"J" Frames	CED-G/E-3 and CED-G/E-4
	Strip Plies	DICE-G/E-1
	Cut-outs	DICE-G/E-2
	Cut-out Doublers	DICE-G/E-4
	Assembly (Mechanical)	CED-MFA-2 and CED-MFA-3
Lightweight/High Complexity Cocured	Skin	CED-G/E-7 and CED-G/E-8
	"J" Stringers	CED-G/E-3 and CED-G/E-4
	"J" Frames	CED-G/E-3 and CED-G/E-4
	Strip Plies	DICE-G/E-1
	Cut-outs	DICE-G/E-2
	Cut-out Doublers	DICE-G/E-4
	Assembly (Cocured)	CED-G/E-10
Moderate Weight/ Moderate Complexity 4 Stringers/3 Frames	Skin	CED-G/E-7 and CED-G/E-8
	"J" Stringers	CED-G/E-3 and CED-G/E-4
	"J" Frames	CED-G/E-3 and CED-G/E-4
	Strip Plies	DICE-G/E-1
	Cut-outs	DICE-G/E-2
	Cut-out Doublers	DICE-G/E-4
	Assembly (Cocured)	CED-G/E-10
Moderate Weight/ Moderate Complexity 3 Stringers/3 Frames	Skin	CED-G/E-7 and CED-G/E-8
	"J" Stringers	CED-G/E-3 and CED-G/E-4
	"J" Frames	CED-G/E-3 and CED-G/E-4
	Strip Plies	DICE-G/E-1
	Cut-outs	DICE-G/E-2
	Cut-out Doublers	DICE-G/E-4
	Assembly (Cocured)	CED-G/E-10
Minimum Part Count	Skin	CED-G/E-7 and CED-G/E-8
	"J" Frames	CED-G/E-3 and CED-G/E-4
	Strip Plies	DICE-G/E-1
	Assembly	CED-G/E-10

- Cost comparisons of similar discrete parts from different materials will be of greatest value at the preliminary design stage where significant leverage exists to achieve low cost
- Cost comparison of similar discrete parts from different materials are of limited value to detail designers who have already been directed to use a particular material
- Demonstrated selection criteria of dollars/pound weight saved
- Fully demonstrated use of MC/DG in developing cost/weight effective designs
- Wider coverage needed to expand data base for basic and additional manufacturing technologies, e.g., machining and extrusions.

With regard to the presentation of the manufacturing technology man-hour data, the following conclusions were arrived at by the aerospace companies:

- Utilized costing methodology, developed program dollar costs, used material, labor, and tooling costs
- Cost/weight summary chart and recommendations are of particular merit.

The trade study decision flows for the cost analysing using the MC/DG for each of the fuselage panels are shown in Figures 24, 25, and 26.

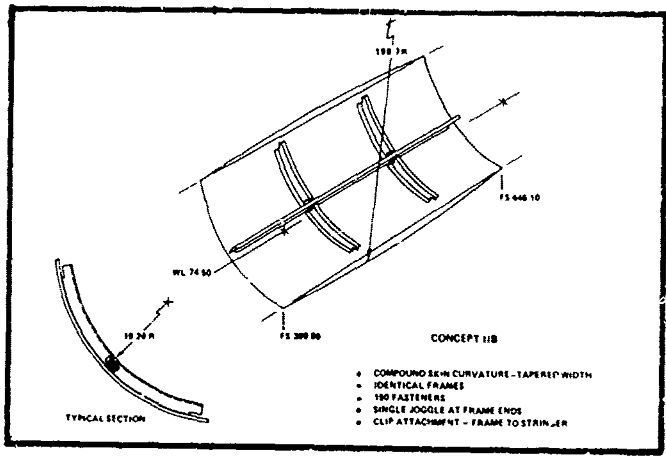


SKIN

Cost Item	Format Number
• Skin	CED-A-20

RESULT: Recurring and non-recurring tooling cost (man-hours) for skin (a)

Cost ...
• Fra...
- ...
- ...
RESU...



SKIN

Cost Item	Format Number
• Skin	CED-A-21

RESULT: Recurring and non-recurring tooling cost (man-hours) for skin. (a)

Cost
• Fr...
-
-
• St...
-
• Cl...
RESU...

A

ASSEMBLY

Cost Item	Format Number
• Installation of Rivets (Including Sealing Requirements)	CED-MFA-1 (Recurring) CED-MFA-3 (NRTC)

RESULT Recurring and non-recurring tooling cost (man-hours) for assembly of panel. (c)

TOTAL

Add man-hours (a), (b), and (c)

RESULT: Total manufacturing cost (man-hours) for concept studied.

B

ASSEMBLY

Cost Item	Format Number
• Installation of Rivets (Including Sealing Requirements)	CED-MFA-1 (Recurring) CED-MFA-3 (NRTC)

RESULT: Recurring and non-recurring tooling cost (man-hours) for assembly of panel. (c)

TOTAL

Add man-hours (a), (b), and (c)

RESULT: Total manufacturing cost (man-hours) for concept studied.

FIGURE 24.

ALUMINUM TRADE-STUDY FLOW

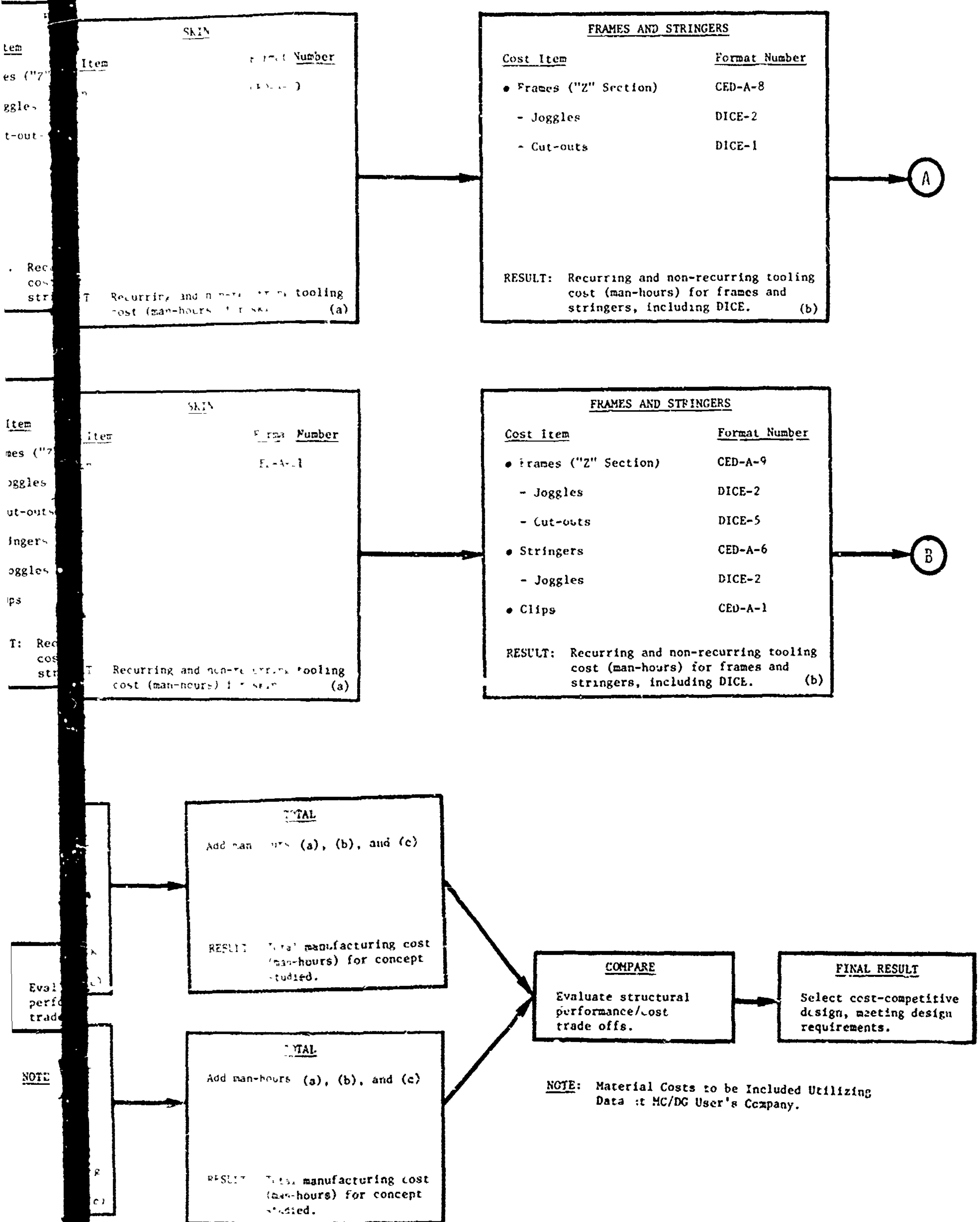
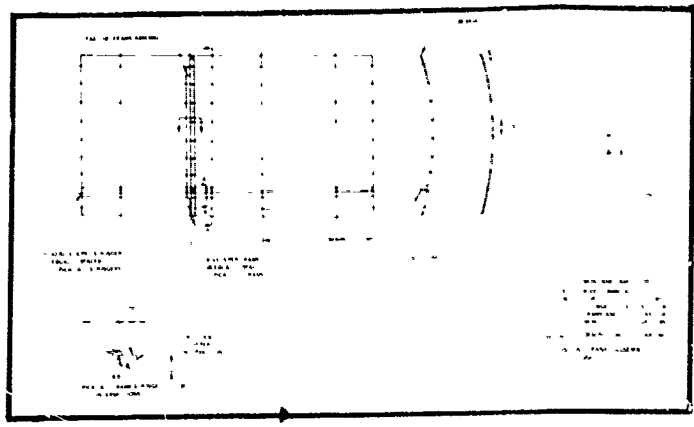


FIGURE 24.

ALUMINUM TRADE-STUDY FLOW



SKIN

Cost Item	Format Number
• Skin	CED-T-7
- Trim After Forming	DICE-13

RESULT: Recurring and non-recurring tooling cost (man-hours) for skin. (a)

Cost Ite

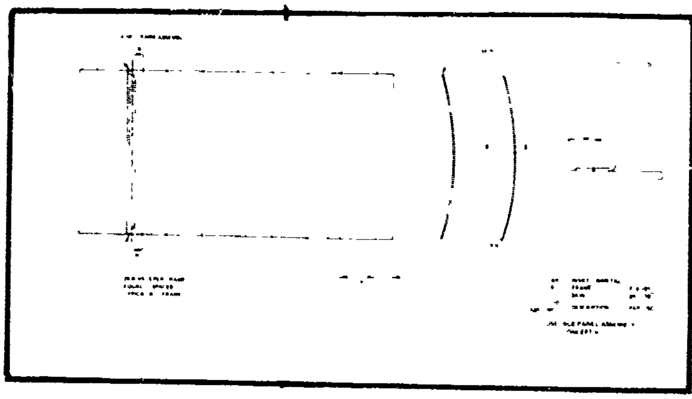
• Frames

• Frame

• String

• Clip

RESULT



SKIN

Cost Item	Format Number
• Skin	CED-T-7
- Trim After Forming	DICE-13

RESULT: Recurring and non-recurring tooling cost (man-hours) for skin (a)

Cost It

• Frame

RESULT

A

ASSEMBLY

Cost Item	Format Number
• Panel--Installation of Rivets (Including Sealing Requirements)	CED-MFA-2 and CED-MFA-3

RESULT: Recurring and non-recurring tooling cost (man-hours) for assembly of panel. (c)

TOTAL

Add man-hours (a), (b), and (c)

RESULT. Total manufacturing cost (man-hours) for concept studied.

B

ASSEMBLY

Cost Item	Format Number
• Frame--Installation of Rivets (Including Sealing Requirements)	CED-MFA-2 and CED-MFA-3
• Panel--Installation of Rivets (Including Sealing Requirements)	CED-MFA-2 and CED-MFA-3

RESULT: Recurring and non-recurring tooling cost (man-hours) for assembly of panel. (c)

TOTAL

Add man-hours (a), (b), and (c)

RESULT: Total manufacturing cost (man-hours) for concept studied.

FIGURE 25.

TITANIUM TRADE-STUDY FLOW

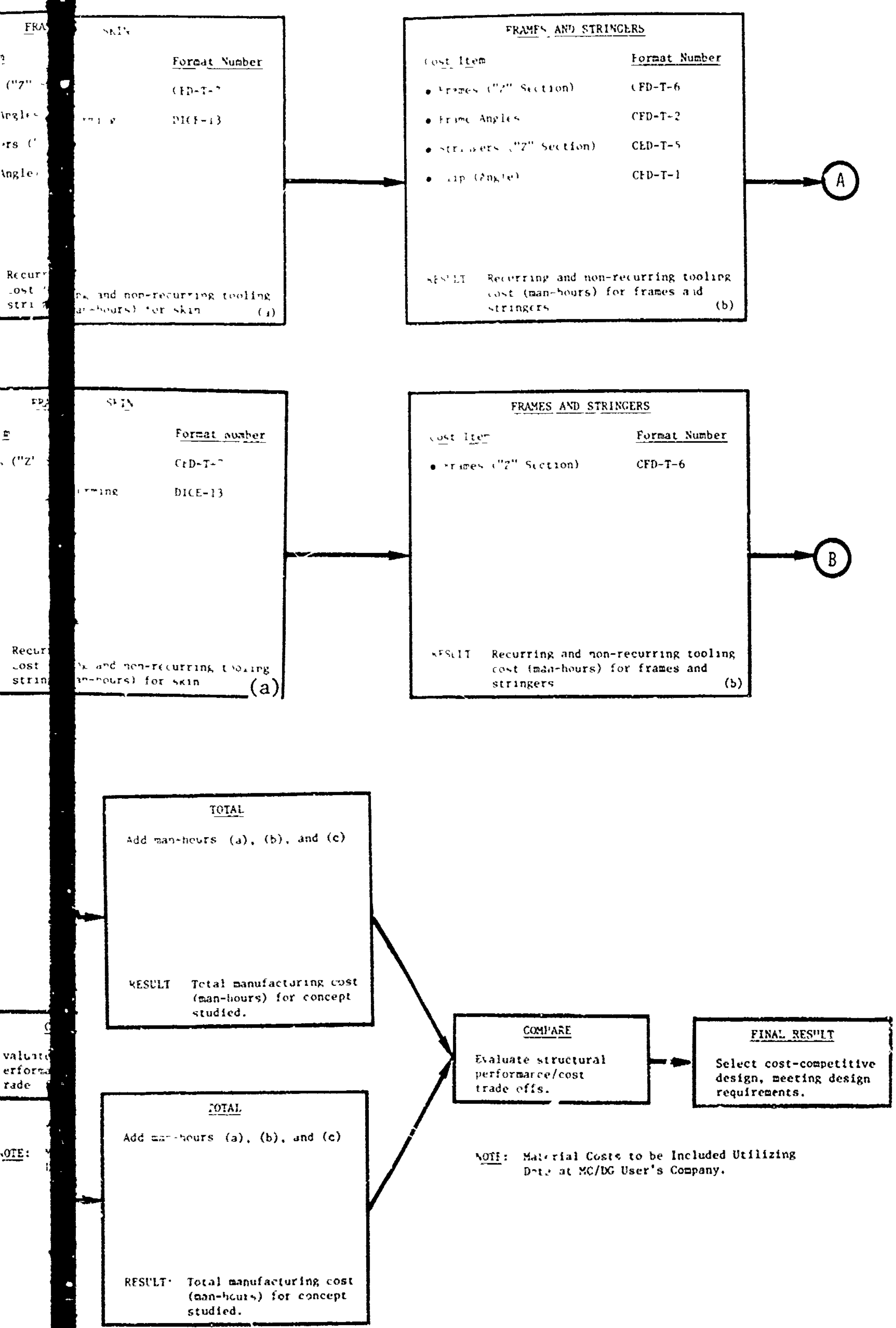
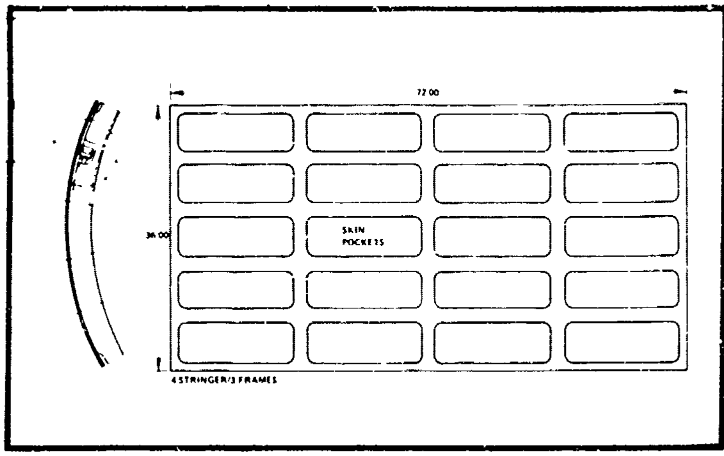


FIGURE 25.

TANIUM TRADE-STUDY FLOW

2



SKIN

Cost Item	Format Number
• Skin	CED-G/E-7 and CED-G/E-8
- Strip plies	DICE-G/E-1

RESULT: Recurring and non-recurring tooling cost (man-hours) for skin (a)

Cost I

• Fra

- S

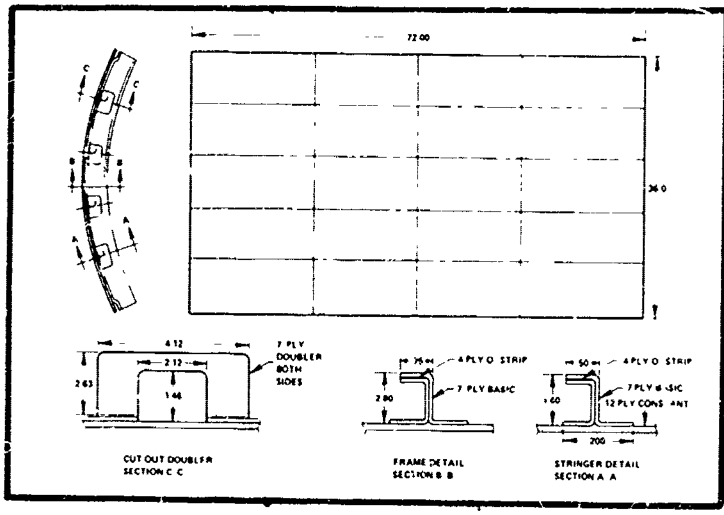
- C

- C

• Str

- S

RESULT



SKIN

Cost Item	Format Number
• Skin	CED-G/E-7 and CED-G/E-8

RESULT: Recurring and non-recurring tooling cost (man-hours) for skin. (a)

Cost

• Fra

- S

- C

- C

• Str

- S

RESUL

A

ASSEMBLY

Cost Item	Format Number
• Assembly and bagging	CED-G/E-10

RESULT: Recurring and non-recurring tooling cost (man-hours) for assembly of panel. (c)

TOTAL

Add man-hours (a), (b), and (c)

RESULT: Total manufacturing cost (man-hours) for concept studied.

B

ASSEMBLY

Cost Item	Format Number
• Assembly and bagging	CED-G/E-10

RESULT: Recurring and non-recurring tooling cost (man-hours) for assembly of panel. (c)

TOTAL

Add man-hours (a), (b), and (c)

RESULT: Total manufacturing cost (man-hours) for concept studied.

FIGURE 26.

ADVANCED COMPOSITE TRADE-STUDY

Cost Item	Format Number
em	Format Number
s ("	CED-G/E-7 and CED-G/E-8
ip p	DICE-G/E-1
-out	
-out	
igers	
ip p	

Re... cost ...urring tooling ...skin. (a)

FRAMES AND STRINGERS

Cost Item	Format Number
• Frames ("J" Section)	CED-G/E-3 and CED-G/E-4
- Strip plies	DICE-G/E-1
- Cut-outs	DICE-G/E-2
- Cut-out doublers	DICE-G/E-4
• Stringers ("J" Section)	CED-G/E-3 and CED-G/E-4
- Strip plies	DICE-G/E-1

RESULT: Recurring and non-recurring tooling cost (man-hours) for skin. (b)

→ (A)

Cost Item	Format Number
tem	Format Number
es ("	CED-C/E-7 and CED-G/E-8
rip p	
t-outs	
t-out	
ngers	
rip p	

Red... co... st... ...rring tooling ...skin. (a)

FRAMES AND STRINGERS

Cost Item	Format Number
• Frames ("J" Section)	CED-G/E-3 and CED-G/E-4
- Strip plies	DICE-G/E-1
- Cut-outs	DICE-G/E-2
- Cut-out Doublers	DICE-G/E-4
• Stringers ("J" Section)	CED-G/E-3 and CED-G/E-4
- Strip plies	DICE-G/E-1

RESULT: Recurring and non-recurring tooling cost (man-hours) for frames and stringers, including DICE. (b)

→ (B)

TOTAL

...hours (a), (b), and (c)

Total manufacturing cost (man-hours) for concept studied.

TOTAL

...hours (a), (b), and (c)

Total manufacturing cost (man-hours) for concept studied.

Evalu... perf... trade...

NOTE:

COMPARE

Evaluate structural performance/cost trade offs.

→

FINAL RESULT

Select cost-competitive design, meeting design requirements.

NOTE: Material Costs to be Included Utilizing Data at HC/DG User's Company.

FIGURE 26.

...FLOW COMPOSITE TRADE-STUDY FLOW

2

SECTION XI

NEED FOR A DYNAMIC COMPUTERIZED MC/DG

A computerized MC/DG can be utilized by designers to perform many tasks determining the impact of often critical information that would otherwise be time consuming, intricate, and bothersome if these effects had to be determined through design charts or utilizing pocket computers. Several examples of this critical information are described below. Volume II of this report describes MC/DG computerization.

One potential application of a "dynamic" computerized MC/DG is to determine the impact of typical price fluctuations with material shortages, energy problems, inflation, and the introduction of production methods which cause changes in the cost of materials and, therefore, the capability to utilize accurate current and/or projected material costs is important in most phases of the design process. This is particularly true in conceptual and preliminary design where attempts are made to utilize a greater percentage of advanced materials, initially expensive. Designers are faced with constantly changing and sometimes reducing material costs influenced by, for example, high volume commercial applications such as with graphite/epoxy and graphite/thermoplastics, and also by new methods employed for producing the reinforcing fibers. These factors can cause a trade study to become rapidly obsolete. A computerized MC/DG will increase the number of trade studies that can be performed and in the application of advanced materials such as composites, more realistic and near optimum comparisons can be made.

The determination of the impact of the location on the learning curve under consideration for the trade study is important. The current MC/DG data are based on unit 200 but the prototype development of aircraft requiring, for example, trade studies for five aircraft only, would have a much higher manufacturing cost based on the learning curve. At the other end of the scale, a large production contract would have a much lower manufacturing cost on the learning curve. Therefore, the designers need to include the impact of aircraft buy quantity. The location of the trade studies on the learning curve is a major factor in management decisions to determine if the return-on-investment for a potential contract is acceptable. With a computerized MC/DG, the designer can quickly determine the point at which it would be practical to respond and management can provide him with a target.

A "dynamic" computerized MC/DG would also be of use in determining the impact of lot release size, especially for lot sizes of less than 25 units. Beyond 25 units for most manufacturing technologies, the impact of lot size is negligible for the purpose of typical trade studies; but as the lot size decreases below 15 units, there is, in most cases, a dramatic impact on cost. With a computerized MC/DG, the designer, in cooperation with the production planning department, can perform trade studies to determine a cost-effective design for various lot releases.

The computer would be an invaluable aid in extrapolating and interpolating dimensional data of airframe parts and assemblies. The function of the computerized MC/DG is, in reality, more of a necessity than of a convenience, because it is not possible for the data base to contain all possible dimensions of aerospace parts. In order to conduct a trade study, the designer must be able to input the part dimensions.

Another useful feature of a computerized MC/DG would be the ability to retrieve earlier design trade-off input and results in a readily usable and recognizable form. This would allow the designer to quickly evaluate past designs and determine what features would be applicable to his present problem and what cost drivers, etc. to avoid. This retrieving feature would be helpful to designers in preparing presentations to management detailing how the chosen configuration for the part under study was developed based on past experience and forecasts. Thus, both the designer and management will be confident that the best part configuration and lowest manufacturing cost has been achieved within the design constraints, e.g., internal structural space available for brackets or beams.

There are more possible uses in design of a dynamic MC/DG but the above examples show that to be a successful design tool, the computerized MC/DG must be a dynamic rather than a static system.

SECTION XII

BENEFITS AND POTENTIAL COST SAVINGS DERIVED THROUGH MC/DG UTILIZATION

The MC/DG represents an important step in arresting the potential erosion of DOD's ability to purchase the required defense systems. This is due to the increasing costs of the systems and the competition of social and other national programs for available funding. The objectives of the MC/DG have been specified earlier in this report (see Section II). However. under the present design and cost estimating procedures in aerospace companies, the limited number of qualified cost analysts available and the time required to conduct adequate cost/weight of trade studies are becoming serious problems. The Air Force and industry have an urgent need to evaluate a greater number of structural concept alternatives in a timely manner prior to commitments to a proposed low-cost design that meets the performance requirements.

The MC/DG, unlike many handbooks, will be applicable at all phases of the program development cycle; for example, at the preliminary design phase or the "window of opportunity" where the greatest leverage exists to reduce cost, i.e., when less than 5 percent of the total program cost has been expended, yet decisions have been made which affect 90 to 95 percent of the total program costs. When the system has been committed to production, only limited opportunities remain to reduce costs.

Utilizing computers, the MC/DG will enable the Air Force and industry to rapidly determine the influence of abrupt or predicted changes in the cost and availability of material resources, cost of capital, etc. The aerospace industry, in the past, has not been considered material intensive, but material sensitive. However, recently, and in the foreseeable future, the availability and cost of materials will have considerable impact on cost. Computerized data can be updated in the MC/DG to rapidly reflect these changes. The impact of such uncertainties of a non-technical nature can be assessed in a more reliable manner than in the past and more credible forecasts can be achieved by determining the impact of various changes on the cost of structural systems. Similarly, a properly maintained and updated MC/DG will reduce the problem of cost data becoming obsolete because of inflation, emerging technologies, and increasing automation in aircraft plants. When complete, the MC/DG will eventually enable manufacturing cost/performance trades to be conducted which reduce operations and maintenance costs. The eventual payoff of utilizing materials, design concepts, and processes which reduce life-cycle costs (LCC) is, of course, the ultimate objective. The importance of LCC becomes clear from the following cost breakdown published several years ago for the B-52 fleet:

	Dollars in Billions
Preliminary Design	0.1
RDT&E	0.5
Acquisition	6.0
Operations	21.0

Using the MC/DG and other structural design guides, it will be possible to examine airframe designs with regard to manufacturing cost, TI&E, fracture mechanics, fracture tolerance, maintainability, etc. The sensitivity of airframe part performance to some manufacturing technologies utilized must also be assessed.

Manufacturing cost data are now becoming available for realistic, credible, cost-effectiveness studies to be conducted when developing structures for a total integrated system meeting the required operational or mission capabilities. Furthermore, the MC/DG will provide an orderly, consistent approach to making cost trade studies upon which the Air Force and industry can agree. This consistency will be helpful in evaluating competitive proposals, and the Air Force will be able to evaluate manufacturing cost/structural performance trade studies very early in the design phase of the program, before major dollar commitments and investments are made. Industry use of the MC/DG will enable the Air Force to evaluate a given structural design more rapidly and efficiently, since it represents a common base of reference from which the analysis was made.

When complete, the MC/DG is expected to enable the cost impact of emerging manufacturing technologies and materials, developed in DOD programs, to be assessed. The ability of emerging technologies to reduce cost can be presented to designers. Furthermore, the cost drivers associated with the emerging materials or manufacturing technologies can also be identified to the designers and also researchers. These emerging technology cost drivers will be important areas on which to focus future research and development programs and, hence, accelerate their applications. It can also provide a forecasting tool to predict the time frame when new technologies will be available. Many emerging technologies do show promise of potential cost reduction and, therefore, the MC/DG will be an important tool to identify these cost reductions using designer-oriented formats, and the emerging technologies will thus become of greater interest to designers and management than basing their acceptance on structural weight reduction potential alone.

As the MC/DG presents cost drivers through CDE and CED formats, areas in which DOD should consider allocating funds will, therefore, be identified. The MC/DG can, therefore, serve as a planning tool, for example, by identifying the areas in which Integrated Computer-Aided Manufacturing (ICAM) should be directed, i.e., using ICAM to reduce cost drivers.

With the MC/DG becoming available to designers, more trade studies will be possible within the time span available or schedule limitations resulting in more alternative designs being considered to achieve lower costs. Furthermore, opportunities for cost reduction, i.e., by alleviating manufacturing cost drivers, will become evident to designers at an earlier stage in the design process than now possible. The MC/DG will, furthermore, serve as a communications link between design and manufacturing.

With the properly maintained and updated MC/DG, the possibility of manufacturing man-hour data becoming obsolete is reduced.

It is interesting to compare the various design approaches where weight and/or cost controls are applied. The following compares the application of the MC/DG with other methods in controlling weight or cost:

- Design weight control only
  - No cost control
  - Decisions based on lowest weight design
  - Cost increases (upward of 10 percent)

- Decisions based on cost/weight effectiveness
  - Reduces cost generally to within 10 percent of targets
- Design cost control (design-to-cost)
  - With cost control: projected cost generally reduced to within 10 percent
- MC/DG application
  - Projected potential cost savings
    - (a) When applied in preliminary design phase--10 to 15 percent
    - (b) When applied in production or detail design phase--2 to 5 percent.

Based on these projected cost savings, which were determined from discussions with experienced designers at the team-member companies, it is useful to make approximate assessments of the dollar savings represented by these predicted percentages:

Transport Aircraft

- From the Air Force "Manufacturing Cost Reduction Study" (AFML-TM-LT-73-1; January, 1973); Transport Structure Cost Distribution (Figure B-2 in report); see Figure 27.
  - Airframe structure--$2,900,000/ACFT
- Projecting a 2 to 5 percent cost savings over 200 ACFT by utilizing the MC/DG during production design phase:
  - A 2 percent savings = $58,000/ACFT or $11,600,000 for the program
  - A 5 percent savings = $145,000/ACFT or $29,000,000 for the program

Fighter Aircraft

- From the Air Force "Manufacturing Cost Reduction Study" (AFML-TM-LT-73-1; January, 1973); Fighter Structure Cost Distribution (Figure B-14 in report); see Figure 28.
- Projecting a 2 to 5 percent savings over 500 ACFT by utilizing the MC/DG during the production design phase:
  - A 2 percent savings = $4,320,000 for the program
  - A 5 percent savings = $10,800,000 for the program.

The cost savings possible with future supersonic advanced aircraft, which will use larger quantities of steel, titanium, composites,

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  - Reduces cost generally to within 10 percent of targets
- Design cost control (design-to-cost)
  - With cost control: projected cost generally reduced to within 10 percent
- MC/DG application
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<u>Fighter Aircraft</u>

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  - A 2 percent savings = $4,320,000 for the program
  - A 5 percent savings = $10,800,000 for the program.

The cost savings possible with future supersonic advanced aircraft, which will use larger quantities of steel, titanium, composites,

TRANSPORT STRUCTURE WEIGHT AND COST DISTRIBUTION

Reference: AFML-TM-LT-73-1, January, 1973

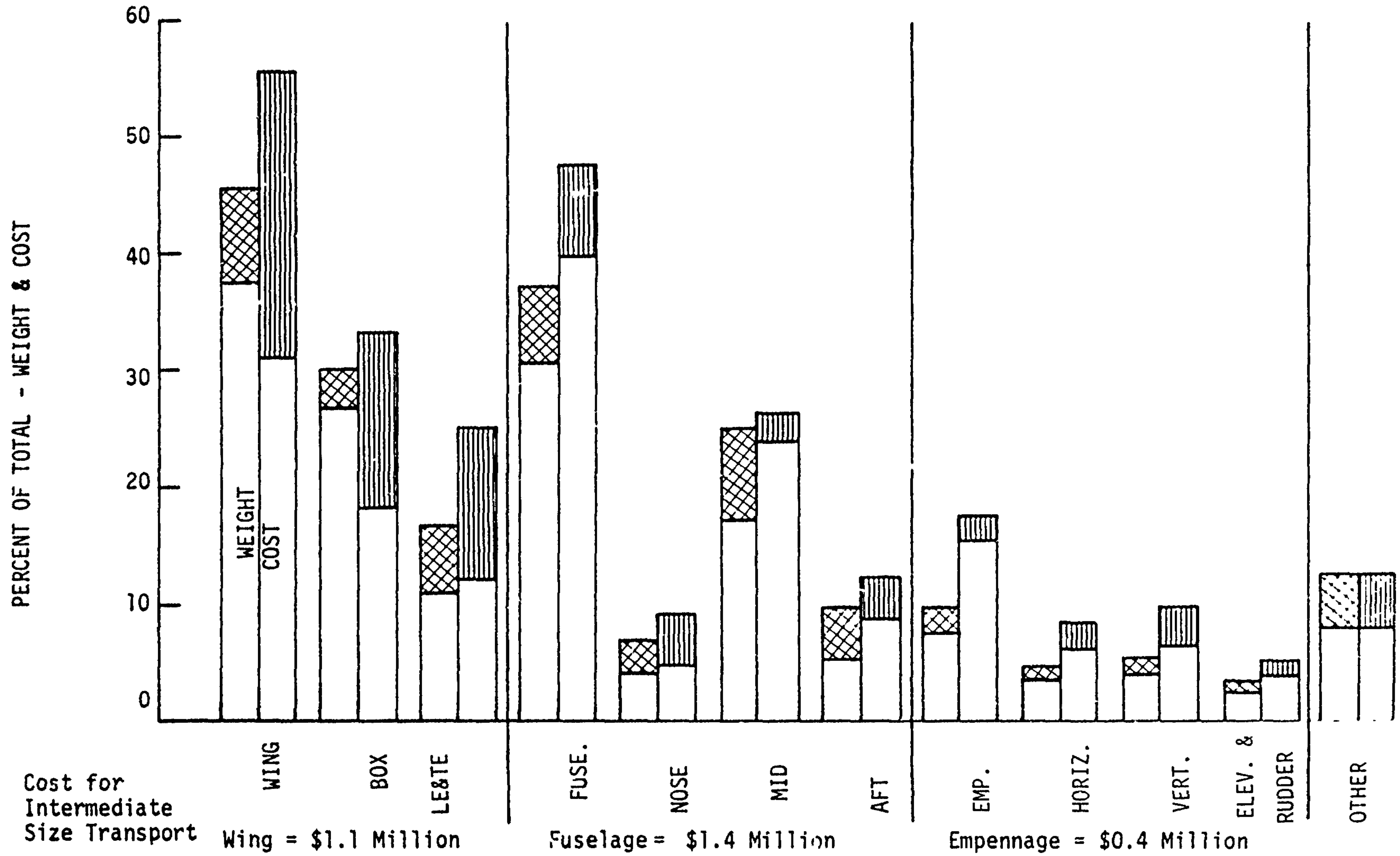

FIGURE 27.

STRUCTURAL WEIGHT AND COST OF MAJOR ASSEMBLIES OF FIGHTER AIRCRAFT AS A PERCENTAGE OF TOTAL STRUCTURAL WEIGHT AND COST

Reference: AFML-TM-LT-73-1, January, 1973

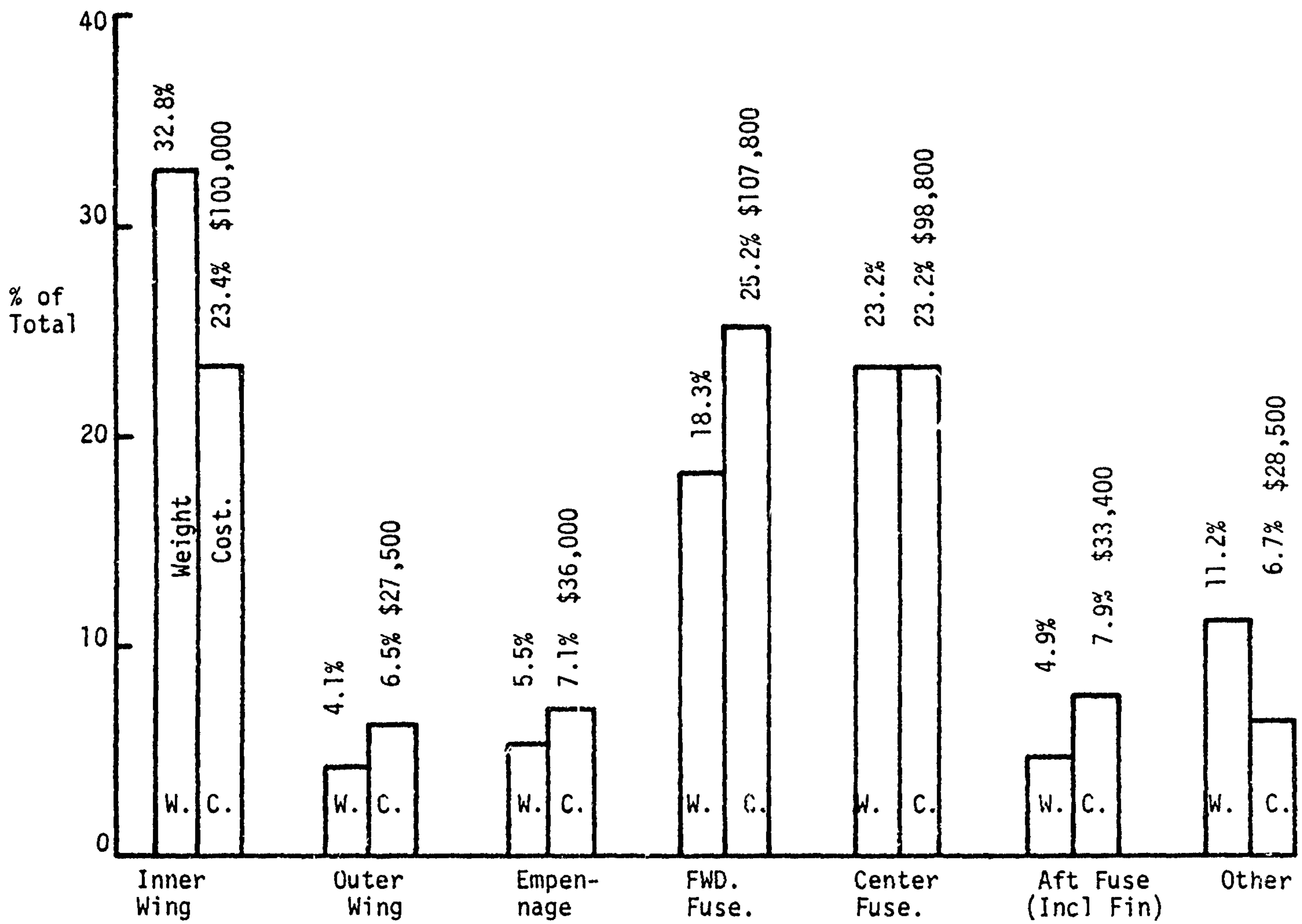

FIGURE 28.

castings, etc., are expected to be greater. With these advanced aircraft, the MC/DG will stimulate the designer to develop innovative structural configurations at the PD stage which utilize the lowest cost manufacturing technologies of both conventional and emerging categories. At present, only a limited number of cost studies can be accomplished on design concepts of aircraft types prior to production release, due to the time-consuming process of obtaining required cost information and estimates. This sometimes results in a more costly design being selected. If it is not possible to accomplish these studies prior to the initial release of the drawings and production go-ahead, the cost associated with making a change becomes so high that many of the cost reduction opportunities are lost.

The MC/DG will be used to support detail design decisions in selecting a design approach at the designer/group leader level. This will allow for relatively fast decisions to be made without the need for higher level direction. Decisions that can be supported with hard facts will be made at the design layout table. A greater breadth will be provided to the designer and the problem of the "point" designer selecting too narrow a scope, resulting in penalties later in the program, will be minimized.

The MC/DG will educate designers of various levels of experience with regard to less costly alternatives which will improve future designs. Important too is that the MC/DG will serve as a vehicle of communication between manufacturing and design and, therefore, will be used to illustrate and support engineering/manufacturing decisions concerning the design approaches which reduce cost.

The MC/DG can serve as an important training document for young and less experienced designers. It can equip them to participate in design-to-lowest cost programs. It will also serve as course material for universities that are sometimes weak in teaching design synthesis and analysis responding to actual engineering design objectives and industry staffing requirements.

It is evident that the MC/DG will serve as an important tool to motivate all members of design teams into a design-to-lowest cost attitude. It will provide cost information to the designer in a manner familiar to him through the designer-oriented formats.

There are a number of additional potential opportunities to utilize the MC/DG data developed stimulating design/manufacturing interaction towards lower cost. These are summarized as follows:

- Pocket-sized book illustrating the high cost drivers representing 80 percent of airframe costs and cross referencing with MC/DG
  - Would contain charts and serve as important tool on the plant floor in discussions on design/manufacturing interaction
- Pocket computer to enable selection of manufacturing processes which avoid or alleviate cost drivers
- Cost advantages of emerging materials and processes can be identified, thus accelerating technology transfer
- MC/DG can be used as a forecasting tool
- MC/DG, which quantitatively identifies cost drivers, can be utilized for planning purposes
- MC/DG can be used to justify acquisition of new equipment, for example, by indicating when equipment should be replaced due to the emergency of a cost driver such as energy requirements.

The MC/DG can be readily used. The designer will develop confidence in the information and, therefore, use it more extensively in his future tasks. The MC/DG will enable the designer to understand the factors affecting cost and the various trades which can be made to reduce costs. The MC/DG can also be used to evaluate cost of potential changes. For example, as new technologies become available, can they be incorporated and be cost effective on an in-production program?

Based on consideration of the above factors, a 5 percent reduction in the cost of design/development is also predicted.

SECTION XIII

THE MC/DG IN EDUCATION

At the present time, it is difficult for the aerospace industry to recruit qualified design engineers. The shortage of engineers is caused by the fact that several new projects are currently under way in industry--both commercial and military. Because of this and other factors, university graduates will have to play an important role in the aerospace industry in the near future.

One of the other factors that will require university graduates to play an increasingly important part is shown in Figure 29. This chart, courtesy of Mr. R. H. Hammer, Boeing Commercial Airplane Company, shows the experience distribution of aerospace industry designers as a function of age. The theoretical curve implies that when an engineer retires, a new person would join the company. This allows time for the inexperienced designer to develop and gain knowledge from the seasoned designers he is associated with. The optimum curve takes into account early retirement and persons transferring from the aerospace industry to other industries. The problem is that the actual situation is not represented by this optimum curve. This is caused by basically two factors. One factor is the large influx of engineers that occurred during World War II and the other is that during layoffs, such as experienced during the late 1960's, and to some extent, in recent years, the last persons entering the aerospace industry were the first ones released. As the curve shows, the average age of designers is approximately 55 years. Furthermore, many experienced engineers are considering early retirement within the next few years and unless some method is developed to transfer the vast amount of knowledge acquired by retiring designers over the years to less experienced designers, a valuable resource will be lost. The MC/DG is one means of documenting and retaining this experience thus achieving the needed transfer of design and manufacturing knowledge.

A further problem is that the industry has been generally disappointed by the lack of design understanding of graduates from our universities and colleges. This has resulted in industry having to conduct expensive and time-consuming training programs for new hires;

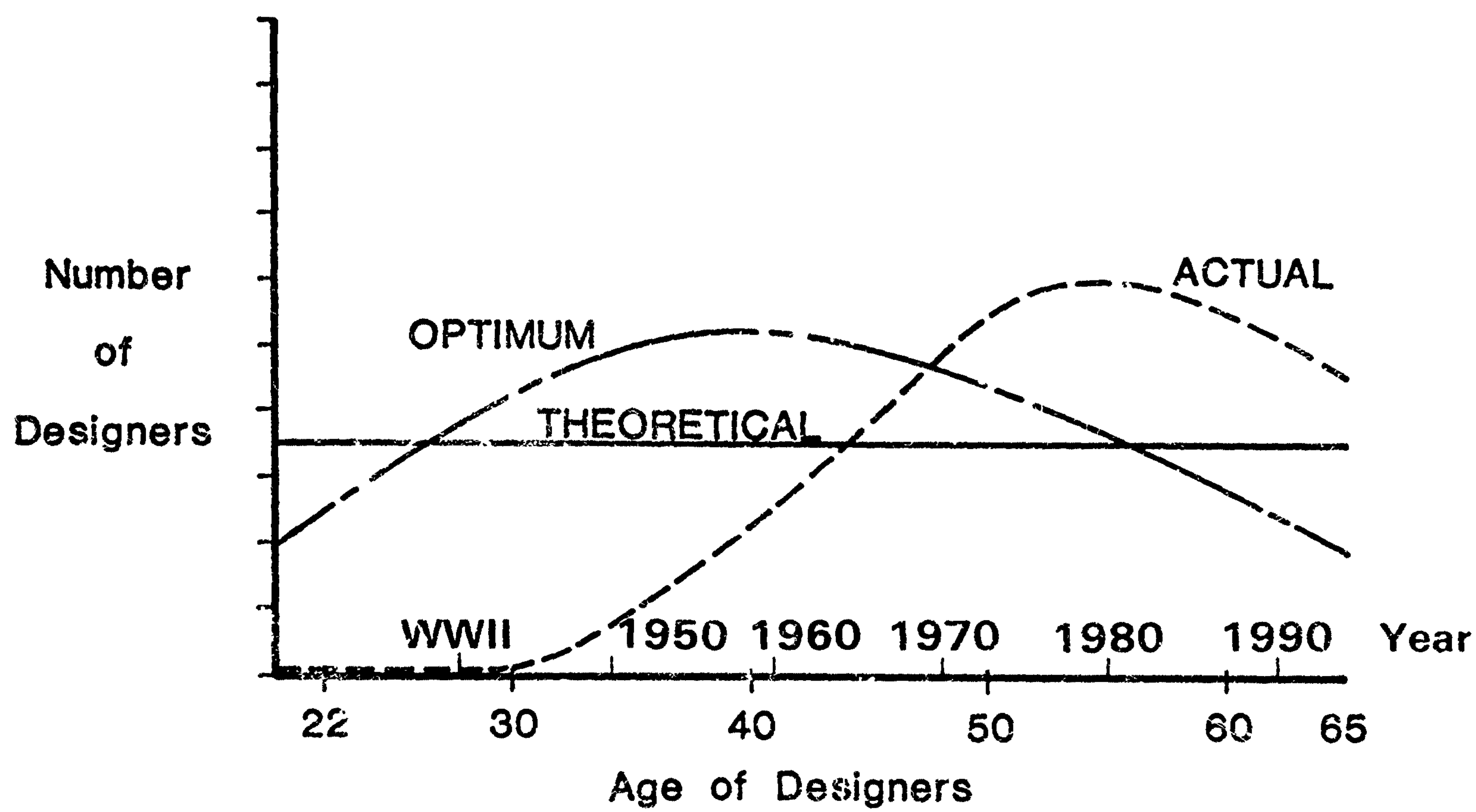

FIGURE 29. EXPERIENCE DISTRIBUTION OF AEROSPACE DESIGNERS

to familiarize them with the design process employed in the aerospace industry. Because the recent graduate will be expected to become involved in design earlier in his career, tools are needed to help speed up the process of transitioning the graduates to the aerospace design team. The MC/DG is such a tool. It can be integrated into the university engineering curricula and industry training programs.

An important area in which the MC/DG can be used for training is in design-to-cost (DTC) programs. The MC/DG introduces the designer to design-to-lowest cost objectives, cost drivers, and methodologies seldom covered in his education. It not only introduces the designer to DTC, but it indicates how to achieve that goal by the airframe application examples contained in the MC/DG, tutorials on the computerized system, and by the actual trade studies conducted and included in the appendices to this report.

The MC/DG introduces the less experienced designer to shop floor activities. The MC/DG provides an insight on how parts are manufactured and will help graduates design a part for lower cost manufacture. This information will improve communication between the less experienced designer and his co-workers, both in the design and manufacturing offices.

In the recent 67th Wilbur and Orville Wright Memorial Lecture, Mr. David S. Lewis* stated that:

> "Members of design teams must have an understanding of several disciplines; the need will be for generalists much like the ones who started aviation on the road to success 75 years ago."

This statement reinforces the need for multidisciplinary and interdisciplinary abilities contained in the following definition of a good "designer" given by Mr. C. Rodwell, Institution of Mechanical Engineers, London, England:

The Qualities of a Good Designer

- Inventiveness--Ability to think or discover valuable, useful ideas or concepts for things or processes to accomplish given objectives
- Engineering analysis--The ability to analyze a given component, system, or process using engineering or scientific principles in order to arrive quickly at meaningful answers

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* "Changing Criteria in Military Aircraft Design", Aerospace Journal Royal Aeronautical Society, March 1979, pp 16-24.

- Engineering science--Thorough knowledge and indepth training in an engineering science specialty
- Interdisciplinary ability--Ability to deal competently and confidently with basic problems or ideas from disciplines outside of the specialty of the designer
- Decision making--The ability to make decisions in the face of uncertainty but with a full and balanced grasp of all the factors involved
- Manufacturing process--Knowledge of, and an appreciation for, the potential and limitations of both old and new manufacturing processes
- Communication skill--Ability to express oneself clearly and persuasively, graphically, and in writing.

Benefits of the MC/DG to university professors and students are summarized below:

<u>To the Professor</u>

- Provides a realistic, easy-to-use source of manufacturing cost information for aerospace discrete parts and subassemblies
- Provides generally applicable, up-to-date source of information, as opposed to specific information from the brochures of vendors
- Facilitates the alignment of theoretical courses to industry staffing requirements by enabling structural performance/manufacturing cost trade studies to be conducted in the classroom
- The computerized MC/DG will provide an additional dimension to computer activities in engineering schools.

<u>To the Student</u>

- Introduces students to systematic methodologies for performing trade studies
- Teaches student the impact of manufacturing technology selection, comparative costs, and manufacturing facility requirements
- Familiarizes students with the use of manufacturing cost data at all stages of the design process
- Aids students in the transition from the classroom or laboratory environment to industry.

The following is a course outline for future designers on the use of the MC/DG:

- Introduction to the background and need of MC/DG
- How MC/DG complements the ever present thrust of "design-to-cost"
- Explanation of CDE, CED, and other information presented in MC/DG
- Illustration of how the MC/DG is used and applied by:
  - Addressing each manufacturing technology
  - Stressing the cost drivers and illustrating these with examples
  - Creating theoretical trade-off situations in airframe structure development
  - Illustrate these with diagrams, engineering drawings, and design criteria.

  Examples of common trade-off situations that confront designers would be used. Direction would be provided on how to proceed and significance of results explained. The trades would be extended to include both cost and weight (requiring strength of materials and structural analysis).

REFERENCES

(1) Summary of Air Force/Industry Manufacturing Cost Reduction Study, Air Force Materials Laboratory, AFML-TM-LT-73-1, January, 1973.

(2) Summary Report on the Low Cost Manufacturing/Design Seminar, Air Force Materials Laboratory, AFML-TM-TL-74-3, December 15, 1973.

(3) Aerospace Cost Savings--Implications for NASA and the Industry, National Materials Advisory Board, National Academy of Sciences, Report No. NMAB-328, 1975.

(4) Computer Aided Manufacturing (CAM) Architecture--Task III, Sheet Metal Fabrication Technology, Air Force Materials Laboratory, Air Force Systems Command, IR 765-6, July, 1977.

☆U.S.Government Printing Office: 1981 — 757-002/344